Collider-Accelerator Department

Safety Assessment Document

Linac, Tandem Van De Graaff, Booster, AGS, RHIC, Transfer Lines and Experimental Areas

Revision 2

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Brookhaven National Laboratory

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1. Chapter One, Introduction

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1.1. Introduction to the C-AD SAD

The Collider-Accelerator Department (C-AD) Safety Analysis Document (SAD) presents a basic statement of the facility's missions, the protections that are afforded the public and worker's health and safety, and the protection of the environment. An overview of the results and conclusions of the safety analysis are contained within Chapter 2. Comprehensiveness of the safety analysis and appropriateness of the Accelerator Safety Envelope are also addressed in Chapter 2. The environment within which the facility was constructed, those facility characteristics that are safety-significant and the methods used to operate the accelerators within the Collider-Accelerator Department are presented in Chapter 3. Chapter 4 documents the analysis, including the methodology, used for identification and mitigation of potential hazards. Chapter 5 is the policy for the engineered and administrative bounding conditions within which the Collider-Accelerator Department operates the accelerators; that is, the policy for an Accelerator Safety Envelope. Detailed limits are prescribed in the Accelerator Safety Envelope (ASE), which is a separate document that relates to the SAD. That is, the SAD is the foundation for the ASE. Chapter 6 describes the quality assurance program at the Collider-Accelerator Department, focusing upon activities that impact protection of the worker, the public or the environment. A description of structural and internal features that facilitate decommissioning of the accelerators and support facilities within the Collider-Accelerator Department is presented in Chapter 7. In Chapter 7, waste management of radiological and hazardous material generation from a future decommissioning operation is discussed within the context of present-day Department of Energy requirements. The final chapter, Chapter 8, includes a summary of acronyms, abbreviations and references with hyperlinks used throughout the document.

Information in this document is available on the web at http://www.rhichome.bnl.gov/AGS/Accel/SND/c-a_sad_and_ase.htm. Related documents such as previously approved Safety Assessment Documents, maps, references and other safety related documents have been archived on the web at http://www.rhichome.bnl.gov/AGS/Accel/SND/chronology_of_eshq_at_c-ad.htm.

1.2. C-AD Mission

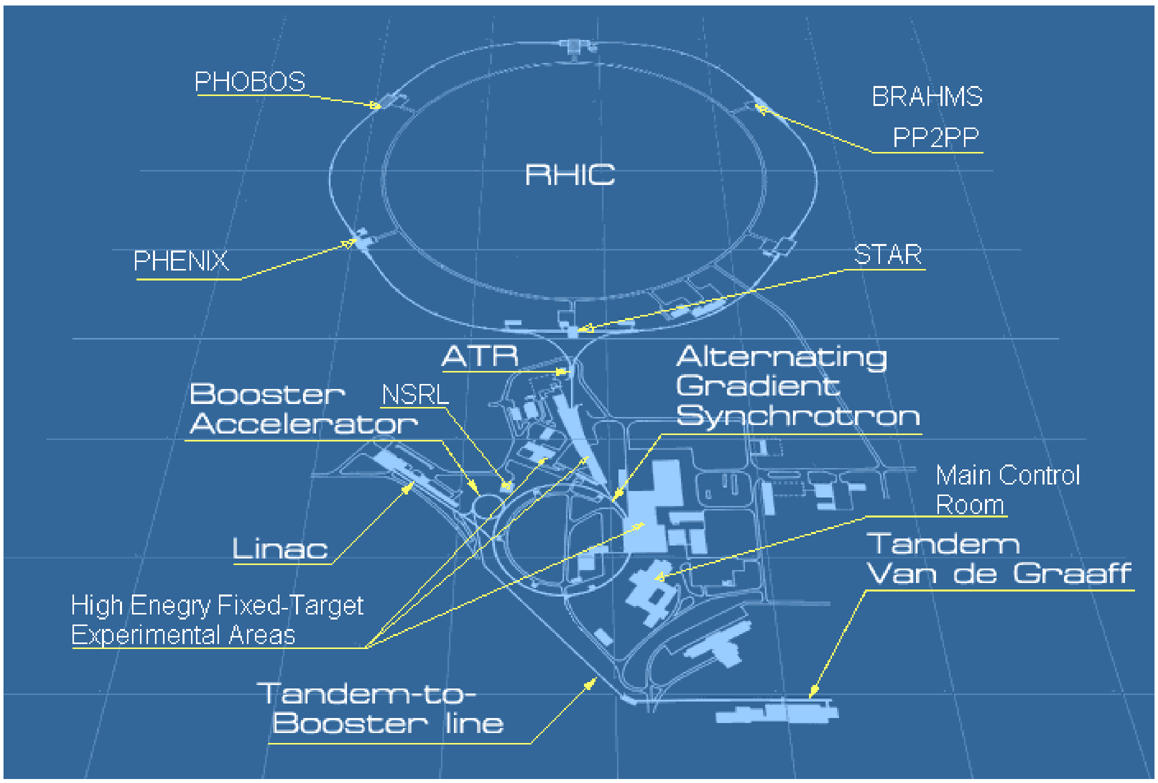
Brookhaven National Laboratory (BNL) is a government-owned, contractor-operated nuclear physics facility that was founded in 1947 to provide a center for nuclear science in the northeastern United States. During the period 1947 to the present, BNL's accelerator facilities have evolved in terms of accelerator type, particle type, target type, particle energy, particle intensity, administering organizations and missions. Today's Collider-Accelerator Department oversees 7 accelerators and 10 experimental areas and is the successor organization to the Accelerator Department, Booster Project, RHIC Project, BAF Project and AGS Department. The current missions of the Collider-Accelerator Department are:

- to develop, improve and operate the suite of particle / heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL
- to support the experimental program including design, construction and operation of the beam transports to the experiments plus support of detector and research needs of the experiments
- to design and construct new accelerator facilities in support of the BNL and national missions
- to achieve excellence in environmental responsibility and safety in all C-A Department operations

The C-A Department supports an international user community of over 2000 scientists. The department performs all these functions in an environmentally responsible and safe manner under a rigorous conduct of operations approach.

Figure 1.2.a illustrates the various accelerators that make up the complex and shows the facilities that connect them.

Figure 1.2.a Accelerators and the Collider within C-AD Site



The Tandem Van de Graaff (TVDG) facility, commissioned in 1970, houses two TVDG accelerators that provide low-energy heavy-ion beams for injection to the Booster through a beam transfer line, or they provide light and heavy ion beams for technological and industrial applications within local target halls. The TVDG accelerators use static electricity to accelerate atoms after removing some of their negatively charged electrons, which are in a cloud around the nucleus. An atom with a charge imbalance is called an ion. A partial lack of electrons gives each ion a strong positive charge. Two separate Tandems give billions of these ions a boost of energy, sending them on their way towards the Booster accelerator or directly to experiments in the TVDG target rooms.

Completed in 1991, the Tandem-to-Booster line (TtB) extends the beam line from the TVDG to the Booster accelerator. The TtB extended an existing beam line known as the Heavy Ion Transfer Line (HITL) that directly injected heavy ions from TVDG into Alternating Gradient Synchrotron (AGS) accelerator from 1986 to 1991. In the current mode of operations, bunches of ions leave the TVDG at about 5% the speed of light and enter the TtB. They travel unimpeded through a vacuum pipe. Magnets are used along the TtB to steer the beam bunches into the Booster. The ions are further stripped of outer shell electrons by passing through a metallic foil prior to entering the Booster.

In addition to heavy ions, some experiments require protons. For these experiments, negatively charged hydrogen ions are supplied to the Booster from a 200 million-electron-volt (MeV) Linac, which was completed in 1970. Negatively charged hydrogen ions from the Linac are transferred to the Booster and stripped of their two electrons to become bare protons as they enter Booster. Linac also supplies protons to the Brookhaven Linac Isotope Producer (BLIP) in Building 931. The BLIP facility is used to make radio-chemicals that are transported to Medical Department laboratories and manufactured into radiopharmaceuticals. Prior to 1991, protons from Linac were injected into AGS directly via the High Energy Beam Transport (HEBT) tunnel. The HEBT tunnel continues to exist and is seen in Figure 1.2.a; however, the steering magnets that direct the beam to the AGS have been removed, and the HEBT to AGS interface has been appropriately shielded.

The Booster synchrotron was commissioned in 1991. The Booster is a powerful compact circular accelerator that provides positively charged ions more energy by having them "surf ride" on the downhill slope of radio-frequency electromagnetic waves. The ions are propelled forward at higher and higher speeds, getting closer and closer to the speed of light. The Booster feeds energetic beams into another accelerator, the Alternating Gradient Synchrotron (AGS), or into an experimental area, the NASA Space Radiation Laboratory (NSRL). Typical energies of particles at Booster extraction are 1.5 GeV for protons, 0.1 to 1.1 GeV per nucleon for Fe ions and up to 0.35 GeV per nucleon for Au ions.

Commissioned in 2003, the NSRL is a national facility for research in the diverse field of biological effects of high-proton number, high-energy particles. The NSRL's design is broad and diverse to allow pursuits of a variety of aspects in the field of biological effects. At the same time, the facility is capable of answering the most basic question in this field, which is quantifying the risk to humans in different shielding environments from exposure to ionizing particles in galactic cosmic rays. NSRL is not an accelerator, rather it is a beam line and target hall that extends from the Booster and it includes experimental support facilities.

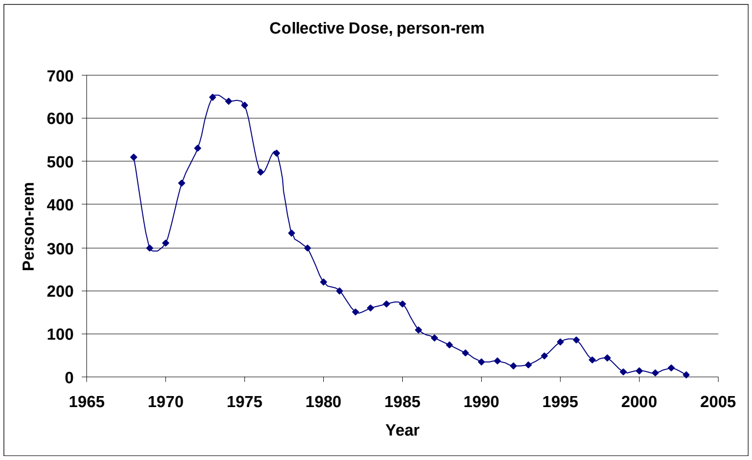
The AGS was commissioned in 1960. The AGS is the heart of the accelerator complex and more information about its capabilities is presented in the sections that follow.

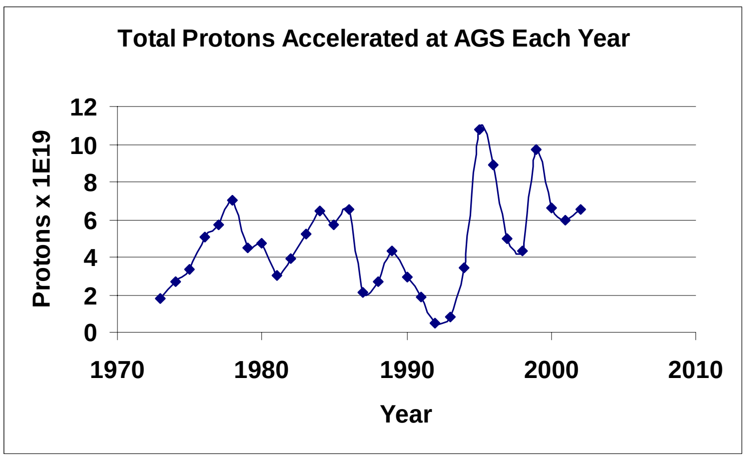
As ions enter the AGS from the Booster, they travel at about 37% the speed of light and they are further stripped of electrons making them more positively charged. As they whirl around the AGS, the ions get even more energy until they are traveling at 99.7% the speed of light.

In 1960, the AGS was developed and first operated at its full energy of 33 GeV for protons. Originally developed as a proton accelerator, the AGS was adapted to accelerate heavy ions in addition to protons in 1986. In 1986, the AGS accelerated protons at an intensity of 15 teraprotons (TP) per AGS pulse to energies of 33 GeV. The injection intensity available to the AGS since 1970 from the Linac injection source has been 150 TP per AGS pulse. AGS pulses are normally repeated every 1.8 to 5 seconds. Until 1991, the AGS lacked the ability to capture and accelerate this intensity of protons from Linac since beam loss, radiation burdens to personnel, and equipment damage prevented operation at this intensity. In 1991, the Booster was constructed to provide additional intensity capabilities to the AGS and allow the AGS to achieve energies for heavy ions that would permit extraction at high enough energy and intensity to inject measurable amounts of beam into the Relativistic Heavy Ion Collider (RHIC). Since installation of the Booster, accelerated protons in AGS have achieved a beam intensity of 80 TP per pulse at maximum energy. In the near future, the AGS will be able to routinely accelerate 100 TP per pulse.

Due to continuous improvements in beam transport and control, routine operation and maintenance actions associated with the accelerator facilities continues to result in a reduction in radiation exposures to workers despite the increased intensity. Figure 1.2.b shows this continuous dose reduction graphically during a period of time when the AGS output increased significantly.

Figure 1.2.b Collective Dose Equivalent Experience and Annual Proton History





1.2.1. AGS Slow Extraction (SEB)

The process of creating a slow spill of about 1.5 seconds involves slowly moving the beam in the AGS. Back-leg winding bumps centered on H20 and F7 hold the beam near the H20 electrostatic septum and the F5 septum magnet, allowing it to be slowly peeled out of the accelerator into the Switchyard, where the beam is split into parts while being transported to the target stations. Prior to moving the circulating beam in the AGS Ring, the beam is de-bunched and given an overall larger momentum spread.

1.2.2. AGS Fast Extraction (FEB)

The FEB extraction system performs multiple single-bunch extraction of either a heavy-ion beam or a polarized-proton beam for RHIC through the AGS-to-RHIC transfer line or a high intensity proton beam to the V-target at a rate of 30 hertz up to 8 times per AGS cycle. For experiments off the V target, the FEB extracts a 50-nanosecond bunched proton beam up to full energy and intensity and performs single-bunch multiple-extraction at 33.3 ms intervals up to 12 times per AGS cycle. An AGS cycle typically repeats every 2 to 3 seconds. The remaining bunches at the end of a cycle, if any, have to be de-bunched and be slowly extracted into the SEB channel. As an injector for RHIC, the AGS may accelerate a variable number of bunches per cycle, e.g., three bunches per cycle and transfer individual bunches one by one into the waiting rf buckets in RHIC through the AGS to RHIC transfer line. Each RHIC ring is filled with up to 120 bunches one after another in a few minutes approximately every 5 hours for heavy ions and every 10 hours for protons.

1.2.3. AGS Switchyard

Once the beam is extracted to the AGS Switchyard, it is split into at most 4 beams, which get transported to the four target stations: A, B, C, and D. Beam is bent away from the AGS Ring by about 1.5 milli-radians with the F5 Septum and about 20 milli-radians with the F10 septum. About 12.5 meters from F10, the beam is bent back towards the AGS about 10 milli-radians by the CD1 magnet to provide more clearance between D line and the target building wall (Building 912). Immediately after CD1 there are four quadrupoles that match the external beam emittance to the requirements of the splitting and transport magnets. Basically a parallel beam is created with low dispersion and constant beam size so that it can travel through splitters and Lambertson pitching magnets with minimal beam loss. Since a particle spill from AGS has a higher momentum at the beginning and a lower momentum at the end, about a 1 % difference, the larger bending magnets in the Switchyard have their current ramped down during the spill.

The beam is split into four pieces by 3 electrostatic wire splitters, which run at about 60 to 80 kV and bend the beams by about +/- 0.3 milli-radians each. For each splitter there is a corresponding Lambertson pitching magnet, whose septum is lined up with the shadow created by the wire splitter. These are thin Lambertson magnets, about 60 mils thick, that each bends the beam about 6 to 8 milli-radians vertically.

The Switchyard, which was commissioned in 1979, may receive fast extracted beam using the H-10 system or receive slow extracted beam using the F-10 system. In both cases, beam pulses may repeat as fast as every 1.8 seconds. In the past, as many as 15 secondary beam lines may be arrayed from the four primary fixed targets at A, B, C and D in Building 912. Secondary beams of rare particles arise from striking primary targets with extracted beams. These secondary beams are used in experiments to study the fundamental properties of hadrons and leptons.

1.2.4. AGS Fast Extraction Beam Lines

The fast extraction beam lines consist of the V line, which was commissioned in 1995, the U line which was commissioned in 1971, and the W line, which was commissioned in 1996.

The AGS extracts full intensity fast bunches via the H-10 extraction system into the V beam line and onto a single fixed target, the V target. Extremely short-lived secondary particles, pions and muons, are emitted from the V target and stored in a superconducting ring magnet in Building 919. Experiments in Building 919 are aimed at studying the fundamental properties of leptons.

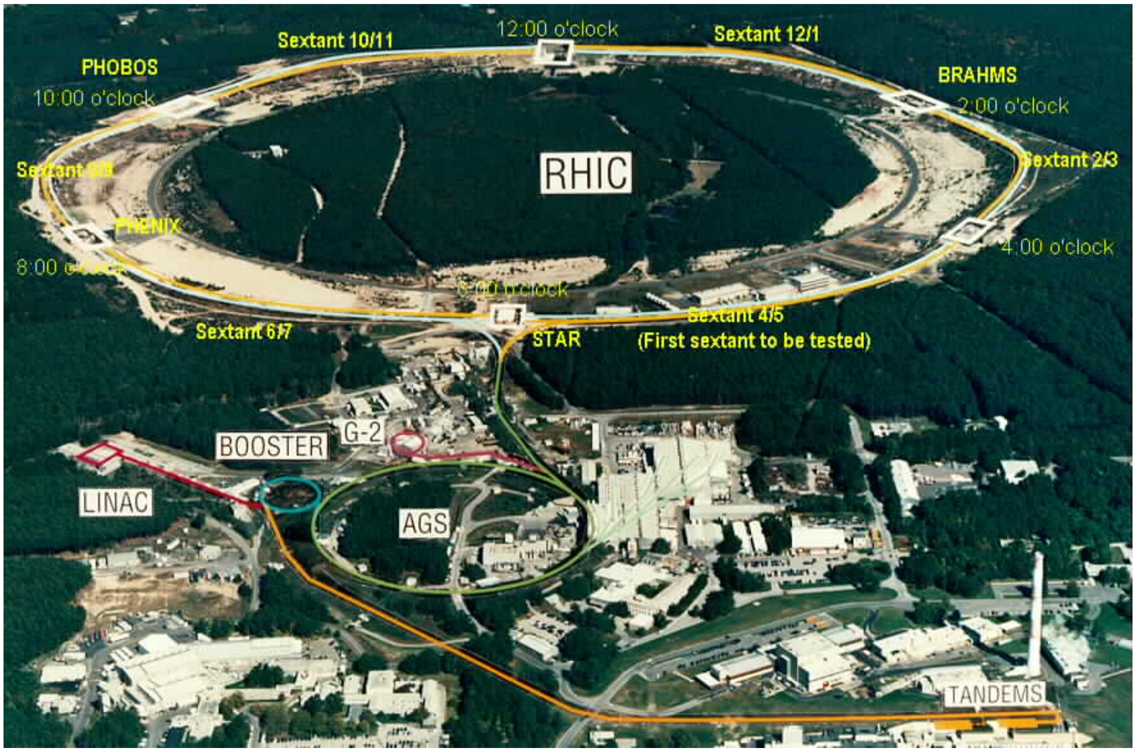
The AGS also extracts low intensity fast bunches via the H-10 extraction system into the U beam line and onto many types of fixed targets in the U line. Most targets receive only a few pulses of beam at reduced intensity. For example, this experimental area is currently used for an applied physics program known as proton radiography.

1.2.5. X and Y Lines and RHIC

The W line is used to transfer beams to the X and Y lines that lead into the RHIC. The AGS-to-RHIC (AtR) transfer line, which was commissioned in 1996, contains the U, V and W beam lines. When the proton beam or heavy ion beam is traveling at top speed in the AGS, it may be steered down the W line toward RHIC. At the end of this line, there is a "fork in the road," where a switching magnet sends the ion bunches down one of two beam lines. Bunches are directed either left to travel clockwise in the RHIC blue ring or right to travel counter-clockwise in the RHIC yellow ring. The RHIC rings were commissioned in 1999. In RHIC, counter-rotating beams are accelerated up to 250 GeV for protons and 100 GeV per nucleon or heavy ions. The two counter rotating beams circulate in RHIC where they are collided into one another at as many as six interaction regions. Currently, four interaction regions are in use by the BRAHMS (Broad Range Hadron Magnetic Spectrometer), PHOBOS (not an acronym), STAR (Solenoid Tracker at RHIC), and PHENIX (Pioneering High Energy Nuclear Interaction eXperiment). See Figure 1.2.4.

Additionally, there is a polarized-hydrogen-gas target (JET) in RHIC and it is used for elastic scattering measurements when polarized proton beams are circulating. The JET target is located at the 12 o'clock intersection point and the two opposing beams in RHIC are separated by ~10 mm instead of colliding. Only one beam at a time interacts with the JET target.

Figure 1.2.5 Accelerators and the Collider Showing the Yellow and Blue Rings



1.3. Basic Safety, Health and Environmental Protections at C-AD

The C-AD accelerators are classified as low-hazard accelerator facilities subject to the requirements of the DOE Accelerator Safety Order, DOE O 420.2A or its successors. These requirements are promulgated in BNL's Accelerator Safety Subject Area. A low-hazard facility is defined to be one with potential for no more than minor on-site and negligible off-site impacts to people and the environment. The possibility of any off-site impacts or major on-site impacts is highly unlikely due to the physical aspects of the C-AD accelerators and collider rings whereby:

- they are dependant upon external energy sources; that is, electric power, that can be easily terminated
- the primary hazard is prompt ionizing radiation that is limited to regions where the beam is maintained and is in existence only when a beam is present

The Collider-Accelerator Department has embraced DOE's Integrated Safety Management System as a basic protection for workers and experimenters. The Laboratory's Standards Based Management System (SBMS) promulgates the requirements of Integrated Safety Management through Subject Areas such as Accelerator Safety, Working with Chemicals, Critiques, Engineering Design, Hazard Analyses, Hazardous Waste Management, Lessons Learned, Work Planning and Control, and Stop Work.

To provide excellent science and advanced technology in a safe and environmentally responsible manner the Collider-Accelerator has, over the past decade, continuously reviewed the hazards of its operations in an effort to identify and accomplish injury and illness prevention opportunities. This effort has resulted in a further formalization of DOE's Integrated Safety Management System under the requirements of the OHSAS 18001 Standard, Occupational Safety and Health Management Systems - Specifications.

The following hazards are significant to the Collider Accelerator Department activities:

- ionizing radiation
- hazardous or toxic materials
- radioactive materials
- electrical energy
- explosive gases and liquids
- oxygen deficiency
- kinetic energy
- potential energy
- thermal energy
- cryogenic temperatures

The C-A Department is committed to identifying hazards during the planning phase of its operations. This is accomplished through implementation of the following operational procedures: C-A-OPM 2.28, C-A Procedure for Enhanced Work Planning; C-A-OPM 2.29, C-A Procedure for Enhanced Work Planning for Experimenters; C-A-OPM 9.1.12, Review of C-A Shielding Design; C-A-OPM 9.1.15, Guideline for Review Criteria for C-A Experiments; C-A-OPM 9.2.1, Reviewing Conventional Safety Aspects of an Experiment; and C-A-OPM 9.3.1, Reviewing Conventional Safety Aspects of an

Accelerator System. As determined by the C-A OSH Management Representative, processes that introduce new hazards that are identified through planning and reviews are also reviewed by members of the Worker Occupational Safety and Health (WOSH) Committee in order to obtain worker input. The AGS Low Hazard Class Determination and the Workplace Hazard Analyses and Risk Assessments serve as the technical baseline through which hazards have been identified. Workplace Hazard Analyses and Risk Assessments are reviewed and updated annually or as required by significant process change.

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, the SBMS Subject Areas are used to:

- define the scope of work in a Work Permit or establish the applicability
- identify the hazards via the Work Permit process and perform a pre-job walk down
- use the Work Permit processes to establish hazard controls and required training
- provide the pre-job briefing and perform the work according to plan/permit
- use the Work Permit feedback process to identify ways to improve next time

In order to guide Users during experiment design and operations, the SBMS Subject Areas are used to:

- determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns
- develop an experimental plan and identify controls
- set up an experiment and obtain Experimental Safety Review Committee concurrence
- approve start-up and perform the experiment according to plan
- determine ways to improve next time

Workers and experimenters at the C-AD work in or near radiological areas. The rules in 10CFR835 establish radiation protection standards, limits and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. These requirements are promulgated in BNL's RadCon Manual. Basic radiation protection systems and programs include:

- access control system
- fixed-location and interlocking area-radiation monitors
- shielding, posting and fencing
- training and qualifications for radiation workers, experimenters and visitors
- personnel monitoring
- radiation work permits
- ALARA reviews of jobs and experiments when needed
- daily radiation surveys using portable radiation monitors
- control of radioactive materials and sources

Basic fire protection includes compliance with DOE fire protection guidelines as well as NFPA's guidelines. The fire protection systems are integrated with the site-wide system. They include automatic fire detection and suppression systems that may consist of automatic Inergen gas suppression, fire-wire detection, smoke detection, fire-rated walls used to separate fire protection zones, automatic wet-pipe and dry-pipe fire suppression, and rapid response capability coverage by the BNL Fire Department. The means of egress for occupancies is in accordance with NFPA 101.

The environmental policy as set forth by Brookhaven National Laboratory in the Environmental Stewardship Policy is the foundation on which the C-A Department manages significant environmental aspects and impacts. Based on the aspect identification and analysis process in the Subject Area, Identification of Significant Environmental Aspects and Impacts, the following aspects are significant to the Collider Accelerator Department activities:

- regulated industrial waste
- hazardous waste
- radioactive waste
- mixed waste
- atmospheric discharge
- liquid effluents
- storage and use of chemicals or radioactive material
- soil activation
- PCBs
- water consumption
- power consumption
- environmental noise

The formal management program for these aspects is called the C-A Environmental Management System (EMS), which complies with ISO 14001. Basic environmental protections that address significant environmental aspects identified by the Environmental Management System include:

- concrete and iron shields to reduce soil activation and sky shine radiation to as low as reasonably achievable
- formal design reviews for modifications

- drawing configuration control
- domestic water supply equipped with back-flow prevention to isolate domestic water supply systems
- systems to hold-up spilled liquids
- systems for ventilation
- waste-handling training and qualifications
- segregation and lock-down of ordinary waste streams, hazardous waste streams and radioactive waste streams
- isolation of storm-sewer drain-lines near the accelerators and experimental areas
- water-impermeable barriers to prevent rainwater from leaching radioactivity from activated soil locations
- Suffolk County Article 12 Code compliance in the design of cooling water systems and piping that contain tritium above the EPA Drinking Water Standard
- compliance with 40CFR61, Subpart H for airborne emissions
- alarms on water systems to detect leaks and alert operations personnel
- isolated closed cooling-water systems to reduce the volume of tritiated water
- process evaluations that describe processes and waste streams in detail, regulatory requirements, waste minimization activities, pollution prevention activities and opportunities for improvement

Management Reviews are used at C-AD to evaluate the overall strategy of the environmental, occupational safety and health (OSH), and self-assessment management systems to determine whether they meet planned performance objectives. The Management Reviews evaluate each management system's ability to meet the overall needs of C-AD and its stakeholders, including its workers and the regulatory authorities. The Review evaluates the need for changes to each management system, including OSH and environmental policy and objectives, and identifies what action is necessary to remedy any deficiencies in a timely manner, including adaptations of other aspects of C-AD's management structure and performance measurement.

The annual Management Review of these ESH management systems provides the feedback direction, including the determination of priorities, for meaningful planning and continual improvement. Senior managers evaluate progress towards C-AD's objectives and corrective action activities and evaluate the effectiveness of follow-up actions from earlier Management Reviews. The frequency and scope of periodic reviews of these management systems is defined according to C-AD's needs and conditions. The Management Review is normally performed annually and normally considers:

- the results of environmental spills, airborne releases, work-related injuries, ill health, diseases and incident investigations
- performance monitoring and measurement and audit activities
- additional internal and external inputs as well as changes, including organizational changes, that could affect each management system

The findings of the Management Review are recorded, posted on the web and formally communicated to the persons responsible for the relevant elements of the management systems so that they may take appropriate action. The results are also communicated to workers and other stakeholders.

2. Chapter Two, Summary/Conclusions

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2.1. An Overview of the Results and Conclusions of the Analysis

A study of site geography, seismology, meteorology, hydrology, demography and adjacent facilities, which includes the C-AD accelerators and experimental areas, shows:

- about 30% of the BNL site is developed with buildings and roads and the balance is undeveloped Pine Barrens forest
- it is the consensus of seismologists that no significant earthquakes are to be expected in the near future
- the climate is temperate
- the Upper Glacial aquifer is a widely used public and private water supply
- radiation from accelerator and experimental area operations will not affect occupants located at the closest occupied non-C-AD facilities

The design criteria, as-built characteristics and supporting systems with safety-significant functions are as follows:

- the design of the accelerators is such that they are capable of accelerating particles that range in mass from protons to Au ions

- nucleon energies within the accelerated particle range from 0.04 to 250 GeV/amu, and beam intensity ranges from 10^3 to 10^{14} particles per pulse; this design provides the most versatile experimental beams and ranges of energies and intensities practicable
- the as-built complex consists of a set of warm-magnet based and superconducting-magnet based accelerators including a Linac, two Tandem van De Graaffs, two synchrotrons and two collider rings
- there are adjacent utility support buildings for power systems, mechanical equipment and cooling systems for the accelerators and the experiments
- these accelerators all have an injection system, an accelerating system, a beam-scraping or internal dump system and an extraction system and they are connected by a series of transfer beam-lines
- the collider rings contain internal extraction systems that send aborted beam to internal beam dumps
- the as-built complex also includes multiple experimental areas that envelop external experimental beam-lines, a superconducting storage ring, beam collimators, target halls, beam stops and an experimental support laboratory
- the collider ring encloses internal beam-collision regions for the RHIC experiments; that is, beam is not extracted out of the RHIC tunnel like at Linac, TVDG, Booster and AGS
- the as-built experimental halls for beam lines and detectors range in size from several thousand square feet to 5 acres, and experimental particle detectors range in cost from hundreds of thousands to hundreds of millions of dollars

- the experimental support laboratory at the NSRL facility also houses equipment for biological sample preparation and dosimetry analysis, and has temporary animal holding facilities
- supporting systems with safety-significant functions include access control systems and the fire protection systems
- the design criteria for the access control systems are that they are redundant, failsafe and have backup; either the system prohibits access or it prevents radiation levels from rising to unacceptable levels
- the access controls systems may also be used to evacuate areas or prohibit entry to areas that have oxygen deficiency
- the design criteria for fire protection systems are that alarms and sprinklers are supervised for circuit trouble and report to the site Fire/Rescue Group, building occupants can hear and/or see alarms throughout the facility, and manual fire alarm pull boxes are located at each exit

Physical features that minimize the presence of hazardous environments and ensure chemical and radiation exposures are kept ALARA during operation, maintenance and facility modification include:

- for radiation: radiation interlocks; gate interlocks; sectionalizing gates; key trees; bio-identification systems; crash cords; audible and visual warnings for beam; fully enclosed primary-beam lines, beam-collision regions or primary-beam target areas; shielding; fencing and posting
- for airborne hazards: once-through and recirculating Biological Safety Cabinets with HEPA filters, chemical hoods, individual laboratory ventilation or target hall

ventilation; short-lived airborne radioactivity is re-circulated in beam lines and accelerators; with the exception of the NSRL target room, stack-type air-emissions from accelerators and beam lines are prevented

- for ALARA: water-resilient caps over activated-soil locations; multi-leg penetrations and labyrinths; re-entrant cavities with movable shields at face of beam stops; and experiment/sample translators or remote operations when applicable
- for electrical safety: compliance with the National Electric Code for non-experimental power-distribution systems;[1] for experimental equipment, a comprehensive set of electrical safety requirements is used, for example, fused circuitry in experimental equipment, emergency-off controls for power, coordinated over-current protection, proper conductor sizing, proper grounding, etc.[2]
- for life-safety and fire protection: manual fire alarm stations; smoke detection; fire alarms; sprinkler protection; fire-hose standpipes; electrical cable insulation and cable trays that meet the National Electrical Code; exits that meet the Life Safety Code; emergency lighting; and fire extinguishers
- for liquid effluents: sumps and sump alarms; drains connected to Sanitary Sewage System; cooling water make-up alarms; no outdoor tritiated-water piping; closed tritiated cooling-water systems; and back-flow preventers on supply water
- for biological safety: Biosafety Level 2 design, Class 2, Type A biological safety cabinets; HEPA filtered air circulation in the NSRL animal laboratory; separate

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[1] During October and November 2003, an inspection at BNL led by the Occupational Health and Safety Administration showed areas where the National Electric Code is not being met. These areas have been identified, and either the condition has been fixed to meet code or the condition has been ameliorated to a safe state in accordance with BNL requirements.
[2] Supplemental Electrical Safety Standard, Collider-Accelerator Department, C-AD Chief Electrical Engineer, November 27, 2000.

ventilation in the cell laboratory; and poured-resinous, seamless floors and washable walls in the animal laboratory

The organizational and management structure the Collider-Accelerator Department and a delineation of responsibilities for safety related actions assure safe operation of the accelerators and experimental areas. Controls for routine operations and emergency conditions are located in the Main Control Room in Building 911, a control room that is staffed around-the-clock by qualified Operators and an Operations Coordinator during operations. Procedures for routine operation and emergency conditions are delineated in the Collider-Accelerator Operations Procedure Manual, which is a controlled document.

Specific operations controls that prevent or mitigate accidents are the beam-loss monitoring systems. The purpose of these machine-protection-systems is to minimize beam loss and to help provide the required beam on target. The Collider-Accelerator Department management requires that inadvertent beam loss occur at levels that are as low as reasonably achievable with operational, economic and community factors taken into account. Specific operations procedures and protocols that prevent or mitigate accidents include Accelerator Safety Envelope procedures, sweep procedures to remove people from beam-enclosures prior to operations, access-control-system testing procedures, beam-loss ALARA procedures, lock-out tag-out procedures, fire-protection system testing protocols, soil-cap inspection procedures, experimental safety check-off lists, radiation safety check-off lists, and work-planning procedures.

Based on analysis, the risk of a serious injury from fire, radiation and electrical hazards at the accelerator and experimental facilities is considered insignificant. This is due to controls that are employed for hazard mitigation. A study of the credible challenges to controls and estimates of consequences in the event of corresponding failure showed that the risk of injury was unlikely. The credible maximum bounding accident scenarios for the C-AD accelerators and experimental areas show less than the design goal of 20 mrem per event to individuals in uncontrolled areas outside the shielded areas.[3] Risks to workers, the public and environment are considered insignificant for routine operations.

2.2. Comprehensiveness of the Safety Analysis

The C-AD SAD for accelerators and experimental areas is consistent with DOE Orders. It closely follows the prescription for an SAD given in Draft Accelerator Safety Implementation Guide for DOE O 420.2A, Safety of Accelerator Facilities, Office of Science, Department of Energy, August 2001.[4]

Fire protection systems and the access control systems are identified as safety significant. The Department's shielding policy is clearly stated.[5] Optimization methods are used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls.[6] Models used for dosimetric predictions in the SAD are described and are verified against actual measurements.[7, 8]

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[3] During routine RHIC operations, the RHIC berm is a Controlled Area. However, the access road into RHIC is uncontrolled. The short uncontrolled portion of road atop the berm is protected by Chipmunk radiation monitors. This area is the single exception to the 20 mrem C-AD shielding policy for protection against faults, and maximum fault dose on the roadway is estimated to be less than 50 mrem if a highly unlikely point loss occurs at that location.

[4] See http://www.rhichome.bnl.gov/AGS/Accel/SND/420Guide/Guide420.pdf

[5] See C-AD SAD Chapter 3, Section 3.2.7.1, Shielding Policy.

[6] See C-AD SAD Appendix 1, 10CFR835 ALARA Design Document for C-AD, http://www.rhichome.bnl.gov/AGS/Accel/SND/c-a_sad_and_ase.htm.

[7] See, for example, http://www.rhichome.bnl.gov/AGS/Accel/SND/C-ADSADReferences/ADtn414.pdf, Radiation Protection Studies during High Intensity Proton Running at AGS, Radiation Exposure around the AGS Ring and in the SEB Experimental Areas.

Significant occupational safety and health aspects and environmental aspects are identified and adequate controls are described.[9, 10, 11, 12]

The C-AD SAD clearly documents the safety and health aspects of all portions of the facility including the accelerators, beam lines, target or beam-collision areas and support facilities. The C-A Department organizational structure and ESH programs for commissioning and operation of C-AD accelerators and experimental areas are adequately described in the C-AD SAD.

2.3. Appropriateness of the Accelerator Safety Envelope

Using Chapter 4 of the C-AD SAD, associated risk assessment forms in Appendix 2, and results of the environmental assessments for these facilities, the Accelerator Safety Envelope (ASE) was developed according to requirements set forth in the BNL SBMS Subject Area, Accelerator Safety.

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[8] See, for example, RHIC Area Monitoring Report for CY 2000, http://www.rhichome.bnl.gov/AGS/Accel/SND/C-ADSADReferences/RHICDoseMeasurements.pdf.

[9] See C-AD Occupational Safety and Health Management System, http://www.rhichome.bnl.gov/AGS/Accel/SND/osh_management_system.htm

[10] See C-AD SAD Chapter 4.

[11] See C-AD Environmental Management System, http://www.rhichome.bnl.gov/AGS/Accel/SND/ems_at_c-a_department.htm.

[12] See Fire Hazards Analyses for C-AD, http://www.rhichome.bnl.gov/AGS/Accel/SND/fire_hazards_analyses.htm.

3. Chapter Three, Site, Facilities and Operations Description

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Index of Figures and Tables

3.1.Characterization of the Site

The site geography is such that BNL is located near the center of Suffolk County, Long Island, about 60 miles east of New York City. Most of the principal facilities are located near the center of the BNL's 5,265-acre site. The developed area is approximately 1,650 acres, consisting of about 500 acres originally developed by the Army, as part of Camp Upton. The developed area is still used for offices and other operational buildings; 200 acres occupied by large, specialized research facilities; 550 acres occupied by outlying facilities, such as the Sewage Treatment Plant, research agricultural fields, housing, and fire breaks; and 400 acres of roads, parking lots, and connecting areas. The balance of the site, approximately 3,600 acres, is largely wooded and it represents native pine barren ecology. See Figure 3.1.

Figure 3.1 Site Overview

The probable occurrence of an earthquake sufficiently intense to damage buildings and structures in the BNL area was investigated as part of the planning for construction of the Relativistic Heavy Ion Collider. It is the consensus of seismologists that no significant earthquakes are to be expected in the near future. No earthquake has yet been recorded in the BNL area with intensity in excess of modified Mercalli III, equivalent to 1- to 8-cm/s^2 acceleration.[1] However, since Long Island lies in a Zone 1 seismic probability area, it has been assumed that an earthquake of Intensity VII could occur, 5.6 on the Richter scale, which is negligible damage of good design and construction.[2] Liquefaction potential of soils at BNL for such an event is negligible given existing soil density and saturation parameters. Thus, structural stability should remain through an event of this magnitude. No active earthquake-producing faults are known in the Long Island area.[3]

The C-A Department reviewed DOE's seismic hazard order and standard (DOE Order 1022-94 and DOE Standard 1023-93) and the Uniform Building Codes for the region and developed guidelines for review of seismic hazards. These guidelines are used for construction of facilities and experiments.

The meteorology is such that prevailing ground level winds at BNL are from the southwest during the summer, from the northwest during the winter, and about equal from these two directions during the spring and fall. Recent meteorological data show the total annual precipitation to be 50 inches. The monthly mean temperature is about 54 °F, ranging from a monthly mean low temperature of 32 °F in January to a monthly mean high temperature of 76 °F

[1] U.S. Department of Energy, Environmental Assessment, Relativistic Heavy Ion Collider at Brookhaven National Laboratory, Upton, New York, DOE/EA# 0508, January 1992.

[2] Pepper, S. "Seismic Event Prediction," Memorandum to T. Sperry, August 6, 1992.

[3] U.S. Department of Energy, Final Environmental Impact Statement, Proton-Proton Storage Accelerator Facility (ISABELLE), DOE/EIS# 0003, August 1978.

in July. The average annual mean temperature shows a continuing trend of increasing annual temperatures. In general, annual mean temperature at BNL has increased 1.9 °F over the last 50 years, compared to a worldwide average surface-temperature increase of 0.55 °F.

The hydrology is such that the BNL site is underlain by approximately 1,300 feet of unconsolidated Pleistocene and Cretaceous sediments overlying Precambrian bedrock. The unconsolidated sediments, subdivided from youngest to oldest, are as follows:

- Upper Pleistocene deposits or Upper Glacial aquifer
- Gardiners Clay or confining unit
- Magothy Formation or Magothy aquifer
- Raritan Formation or Raritan Clay confining unit and Lloyd aquifer

The Upper Glacial aquifer is widely used on Long Island for both private and public water supply. Drinking water and process water supplies at BNL are obtained exclusively from the Upper Glacial aquifer. The Laboratory currently operates six potable water supply wells that can be pumped at rates of 1,200 gpm, and five process supply wells that can be pumped at rates between 50 and 1,200 gpm. During maximum water usage at BNL, up to 6 MGD are pumped from the Upper Glacial aquifer. Most of this water is returned to the aquifer by way of recharge basins or discharge of Sewage Treatment Plant (STP) effluent to the Peconic River. Groundwater in the Upper Glacial aquifer beneath BNL generally exists under unconfined conditions. However, in the areas along the Peconic River where low permeability near surface silt and clay deposits exist, semi-confined conditions may occur. Depth to groundwater varies from several feet below land surface, such as within the lowlands near the Peconic River, to as much as 75 feet in the higher elevation areas located in the central and western portions of the site. The Long Island aquifer system has been designated by the U.S. EPA as a Sole Source Aquifer System, pursuant to Section 1424(e) of the Safe Drinking Water Act. Groundwater in the sole source aquifers underlying the BNL site is classified as "Class GA Fresh Groundwater" by the State of New York (6NYCRR Parts 700-705). The best usage of Class GA groundwater is as a source of potable water supply. As such, federal drinking water standards, NYS Drinking Water Standards and NYS Ambient Water Quality Standards for Class GA groundwater are used as groundwater protection and remediation goals.

For drinking water supplies, federal maximum contaminant levels (MCLs) set forth in 40 CFR 141 and 40 CFR 143 apply. The Laboratory maintains six wells and two water-storage tanks for supplying potable water to Laboratory community. In NYS, the Safe Drinking Water Act requirements pertaining to the distribution and monitoring of public water supplies are promulgated under Part 5 of the NYS Sanitary Code, which is enforced by the SCDHS as an agent for the NYS Department of Health. These regulations are applicable to any water supply that has at least five service connections or regularly serves at least 25 individuals. The Laboratory supplies water to a population of approximately 3,500 employees and visitors and must comply with these regulations. In addition to MCLs, DOE Order 5400.5, Radiation Protection of the Public and Environment, establishes Derived Concentration Guides for radionuclides not covered by existing federal or state regulations.

The BNL groundwater-surveillance program uses monitoring wells, which are not utilized for drinking water supply, that are designed to monitor C-A Department facilities where there is a potential for environmental impact, or in areas where past activities have already degraded groundwater quality. BNL evaluates the potential impact of radiological and nonradiological levels of contamination by comparing analytical results to NYS and DOE reference levels.

The predominant groundwater flow direction is to the south-southeast. The closest BNL potable water supply to C-A Department facilities is supply-well-10 located approximately 2,100 feet to the east. Results from supply well capture zone modeling indicates that under sustained pumping conditions, approximately 8 to 10 years would be required for groundwater to travel from the closest C-A Department facility to supply-well-10. Well 10 has been shutdown since 1999.

The demography is such that about a third of the 1.37 million people that reside in Suffolk County live in Brookhaven Township where the Laboratory is situated. Approximately eight thousand people live within 0.3 miles of the Laboratory’s boundaries.

Funding from the U.S. Department of Energy drives the demography of the BNL site. Brookhaven National Laboratory is a multi-program scientific center that develops and operates large-scale, state-of-the-art research facilities that are beyond the capability of any single university. In carrying out DOE's mission at the Laboratory, BNL's staff conducts its own basic and applied research at the frontiers of science through long-term programs in physics, chemistry, biology, medicine, energy and environmental sciences, and nonproliferation and national security. In addition, Brookhaven's 3,000 scientists, engineers and support staff collaborate and/or meet the needs of the more than 4,000 visiting researchers who come to the Laboratory each year from across the country and around the world.

Today, the Laboratory is home to five Nobel Prize-winning discoveries in physics. The first Nobel Prize for research developed at BNL was awarded in 1957, for a theory on parity conservation. The physics prizes in 1976, 1980 and 1988 were awarded for discoveries made using Brookhaven's Alternating Gradient Synchrotron (AGS), which is part of C-A Department. A chemist at Brookhaven National Laboratory, won the 2002 Nobel Prize in Physics for detecting solar neutrinos, ghostlike particles produced in the nuclear reactions that power the sun.

The AGS is one of the world's premiere particle accelerators and together with the AGS-Booster are the only heavy-ion accelerators for radiation-biology research in the U.S. In addition, the AGS serves as a pre-accelerator for the Laboratory's Relativistic Heavy Ion Collider, which is the world's newest and biggest particle accelerator for nuclear physics research.

Since 1998, Brookhaven Science Associates (BSA), a nonprofit, limited-liability company established in 1997 by Battelle and the Research Foundation of the State University of New York (SUNY) for SUNY at Stony Brook, has operated BNL under contract with the U.S. Department of Energy. BSA's goal is to encourage internationally significant and nationally important science research to be done at Brookhaven, while ensuring the quality of the Long Island environment, the safety of the surrounding community, and the health of the Laboratory's staff and visitors.

Founded in 1977 as the 12th cabinet-level federal department, the U.S. Department of Energy oversees much of the energy-related scientific research in the U.S., through its support of BNL and the eight other national laboratories. The U.S. Department of Energy not only provides the majority of Brookhaven's research dollars and direction, but also it is the government agency responsible for the Laboratory's operations and environmental stewardship.

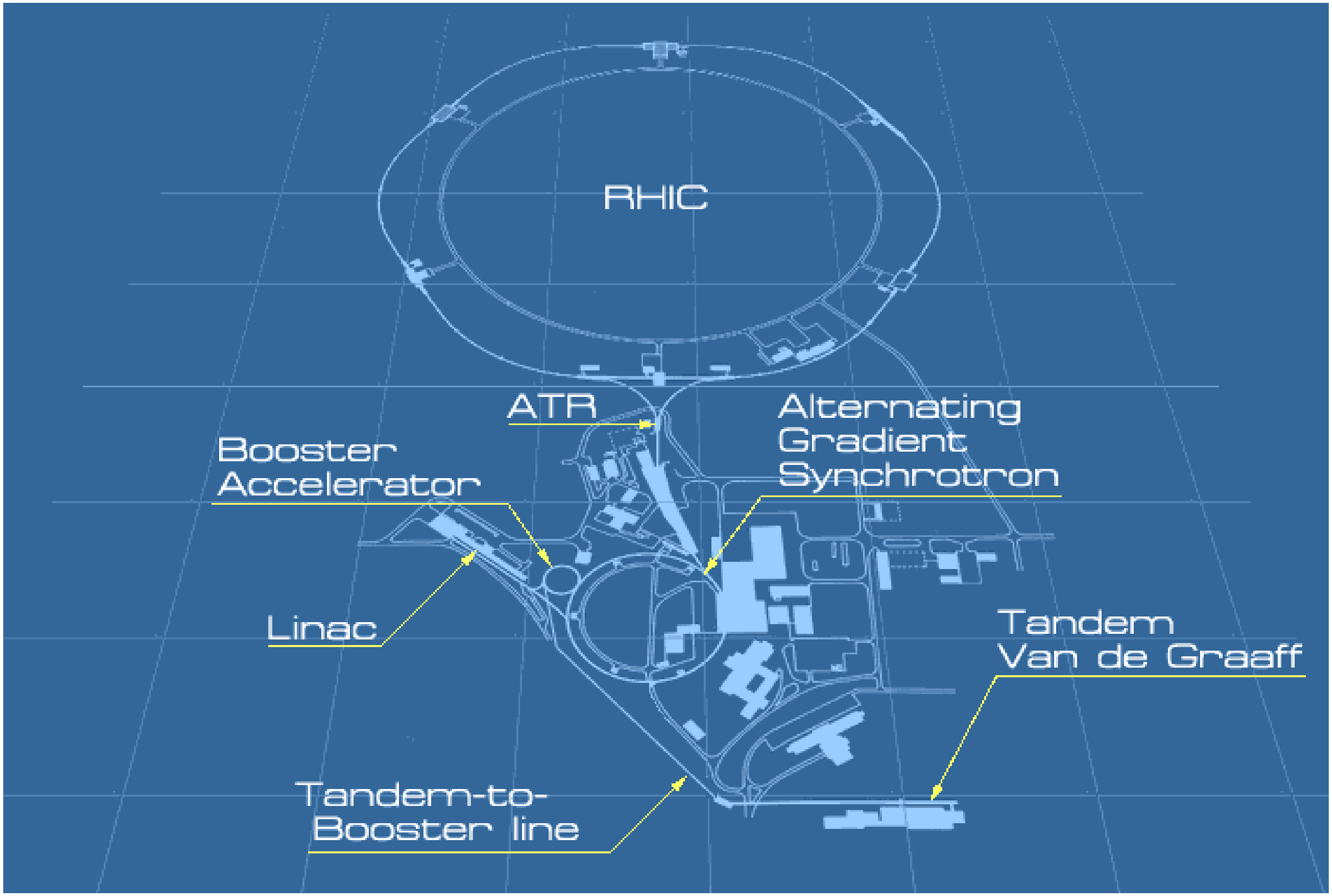
3.1.1.Characterization of the Accelerators and Experimental Facilities

The Collider-Accelerator Department is responsible for over 120 buildings and additional structures such as cooling-water towers and shield-block yards. These facilities are further described in Facility Use Agreements (FUAs). Links to FUAs, facility pictures and the list of Building Managers are located at the C-A Department's ESHQ web site.

Figure 3.1.1.a shows a schematic of the Collide-Accelerator complex. There are seven accelerators in operation. They include:

- two collider rings, which are known as the Relativistic Heavy Ion Collider (RHIC)
- main injector, which is known as the Alternating Gradient Synchrotron (AGS)
- Booster accelerator, which supports the NASA Space Radiation Laboratory (NSRL), AGS and RHIC programs
- pre-injectors known as the Linac and the two Tandem Van De Graaff (TVDG) accelerators

Figure 3.1.1.a Schematic of Collider-Accelerator Complex

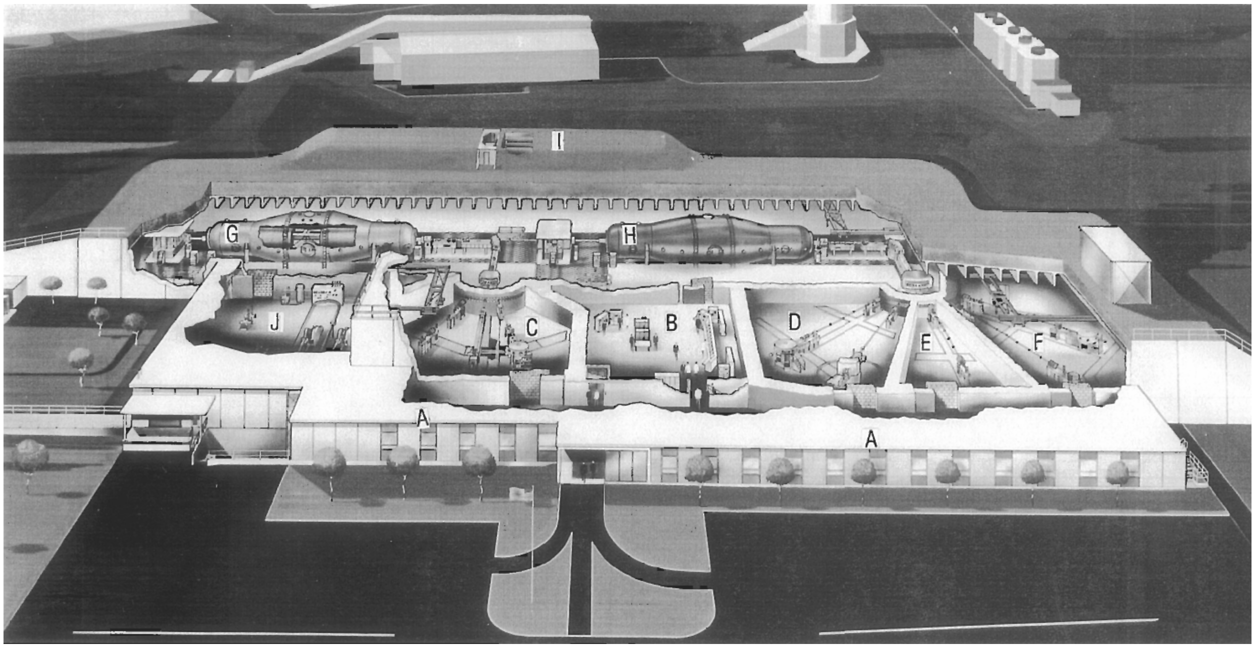


Completed in 1970, the TVDG pre-injector facility was for many years the world's largest electrostatic accelerator facility. It can provide researchers with beams of more than 40 different types of ions that have been stripped of their electrons. Ions ranging from hydrogen to uranium are available. The facility consists of two 15 MeV accelerators, each about 75-feet long, aligned end-to-end. See Figure 3.1.1.b.

Figure 3.1.1.b Tandem Van De Graaff Accelerators

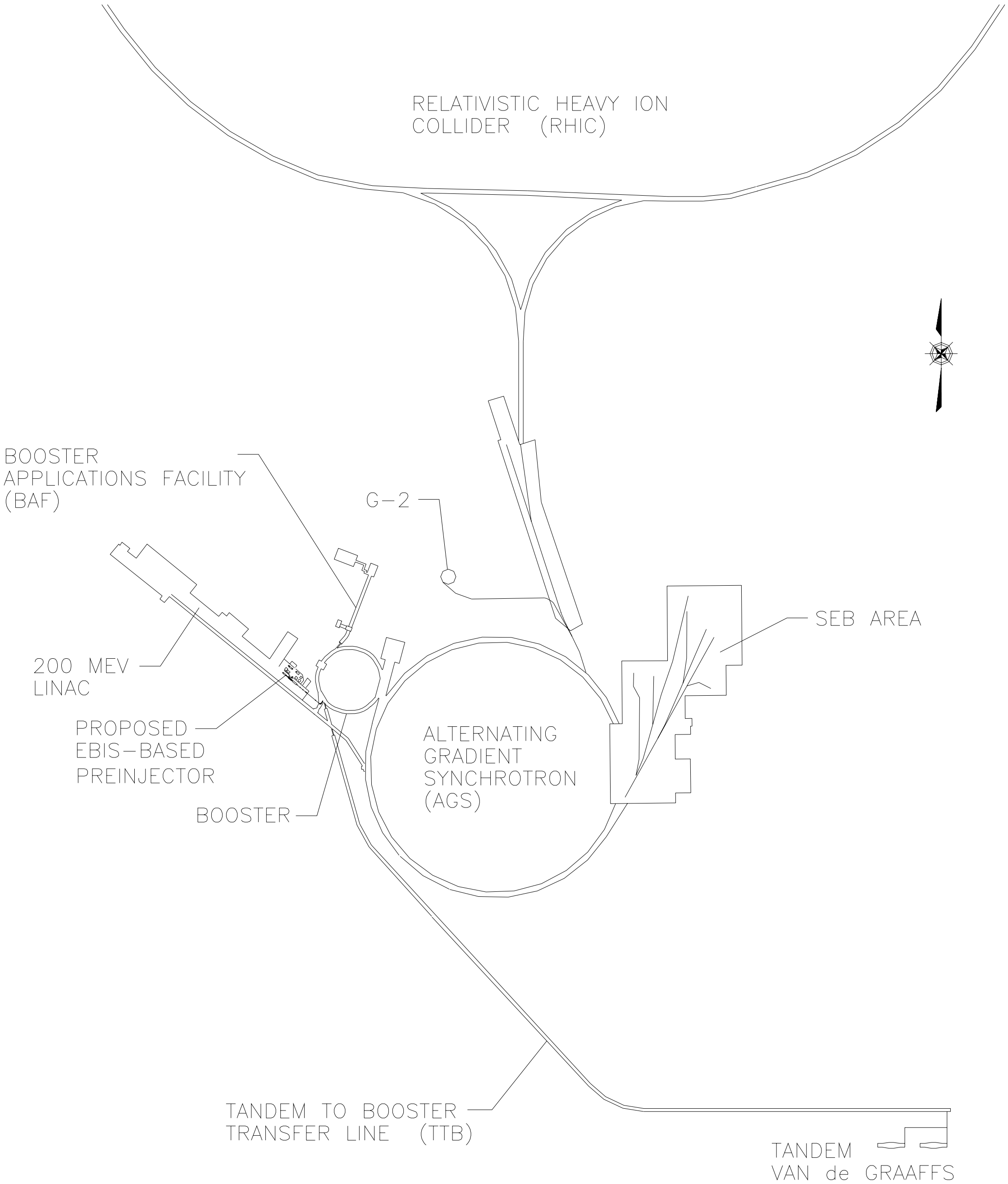
The Radiation Effects Testing and Calibration facility at TVDG is available for the study of space radiation effects, in particular, Single Event Upset (SEU) Testing and Spacecraft Instrument Calibration. The ion energies may range from 29 MeV protons to 385 MeV uranium ions. Ion irradiation and implantation are also available for other ion-beam related applications. Heavy-ion research for nuclear physics was started at the TVDG in 1970. Since 1986, at least one of the accelerators has served as the heavy ion injector for the Booster or AGS. In 1999, heavy ions from the TVDG were transported through the Booster and AGS and into the Relativistic Heavy Ion Collider. Since 2003, TVDG has served as an injector to Booster for supplying heavy ion beams that are extracted from the Booster into the NASA Space Radiation Laboratory (NSRL). The NSRL radiobiology research program is related to the investigation of space radiation on humans and is particularly important for the planning of future long-term deep space flights. The layout of the TVDG facilities is shown in Figure 3.1.1.c.

Figure 3.1.1.c TVDG Facility Layout: Offices/Labs (A), Control Room (B), Target Rooms (C, D, E, F), Accelerators (G, H), Insulating Gas Storage (I), Mechanical Equipment Room (J)



To study heavy-ion collisions at high energies, a 2700-foot tunnel and beam transport system called the Tandem to Booster (TtB) Line were completed in 1991, allowing the delivery of heavy ions from TVDG to the Booster for further acceleration. This line was an extension of the former Heavy Ion Transfer Line (HITL) that allowed for direct injection of heavy ions from TVDG into AGS. The HITL transport system no longer exists; however, the spur tunnel leading directly to AGS is still present. The TtB tunnel was constructed to extend the transport of heavy ions from the Tandem to the Booster because the excellent vacuum levels in the Booster allow partially stripped ions heavier than sulfur to be accelerated to intermediate energies and then fully stripped before AGS injection. This feature ultimately allowed heavy ions of all species to be injected into RHIC for colliding beam physics. The TtB (HTB plus HITL) tunnels are shown in Figure 3.1.1.d.

Figure 3.1.1.d Sketch of Transfer Line for Heavy Ions from TVDG to Booster

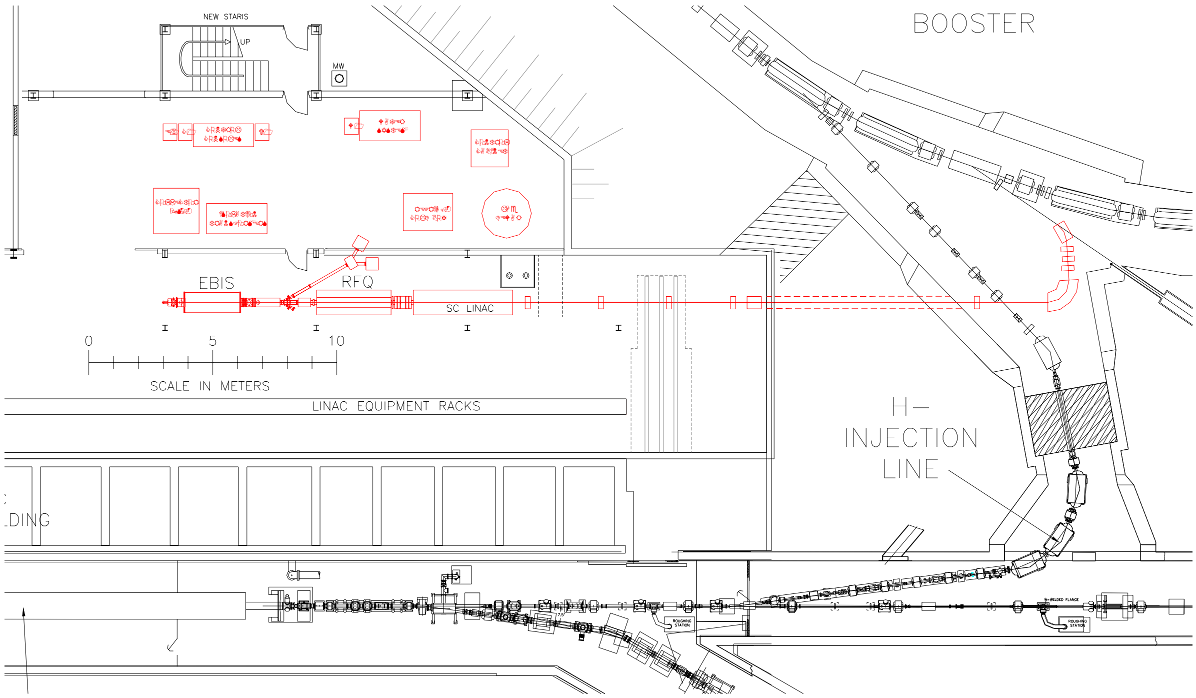


In the near future, a second heavy-ion pre-injector, the Electron Beam Ion Source (EBIS), will be housed in the 200-MeV Linac building with a short tunnel section connecting to the

Booster. The EBIS is small and compact when compared to the TVDG pre-injector facility and the TtB line, and it is intended to replace these facilities.

This new heavy ion pre-injector for RHIC is based on an intermediate charge-state heavy-ion source, a Radio Frequency Quadrupole (RFQ) accelerator and a short superconducting Linac. The highly successful development of an EBIS at BNL now makes it possible to replace the present TVDG with a reliable, low maintenance Linac-based pre-injector. Linac-based pre-injectors are presently used at most accelerator and collider facilities with the exception of RHIC, where the required gold beam intensities could only be met with a Tandem until the recent EBIS development. The high reliability and flexibility of the new Linac-based pre-injector will be an essential component for the long-term success of the RHIC facility. This new EBIS also has the potential for significant future intensity increases, and can produce heavy-ion beams of all species including uranium beams. It could also be used to produce in-house polarized ^3He beams. These capabilities will be critical to the future luminosity upgrades and electron-ion collisions in RHIC. The new RFQ and linac that are used to accelerate beams from the EBIS to energy sufficient for injection into the Booster are both very similar to existing devices already in operation at other facilities. Injection into the Booster will occur at the same location as the existing injection from the Tandem. A sketch of the facility is shown in Figure 3.1.1.e.

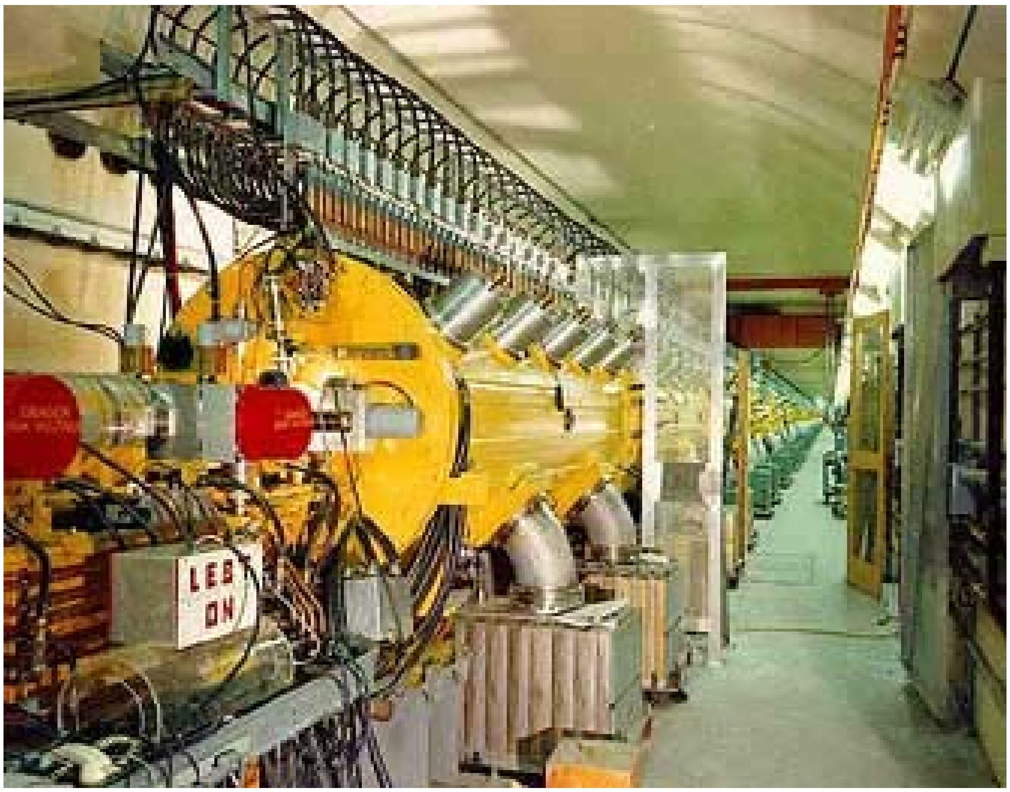
Figure 3.1.1.e Schematic Showing the Planned EBIS Pre-injector (in red) in the Lower Equipment Bay of the 200-MeV Linac



The 200-MeV Linac was designed and built in the late 1960's as a major upgrade to the AGS complex. Before the 200-MeV Linac, a 50-MeV Linac was used to inject protons into the AGS. The 200-MeV Linac's purpose is to provide accelerated high-intensity protons for use at AGS, polarized protons at RHIC, and high-intensity protons at a Medical Department facility known as the Brookhaven Linac Isotope Producer (BLIP). The basic components of the 200-MeV Linac include ion sources, a radiofrequency quadrupole pre-injector and nine accelerator radiofrequency cavities spanning the length of a 460-foot tunnel. The Linac is capable of producing up to a 35-milliampere proton beam at energies up to 200 MeV for injection into the Booster or for the activation of targets at the BLIP. The BLIP targets are used by the Medical

Department to produce radiopharmaceuticals for human studies. The Linac tunnel is shown in Figure 3.1.1.f.

Figure 3.1.1.f Linac Tunnel

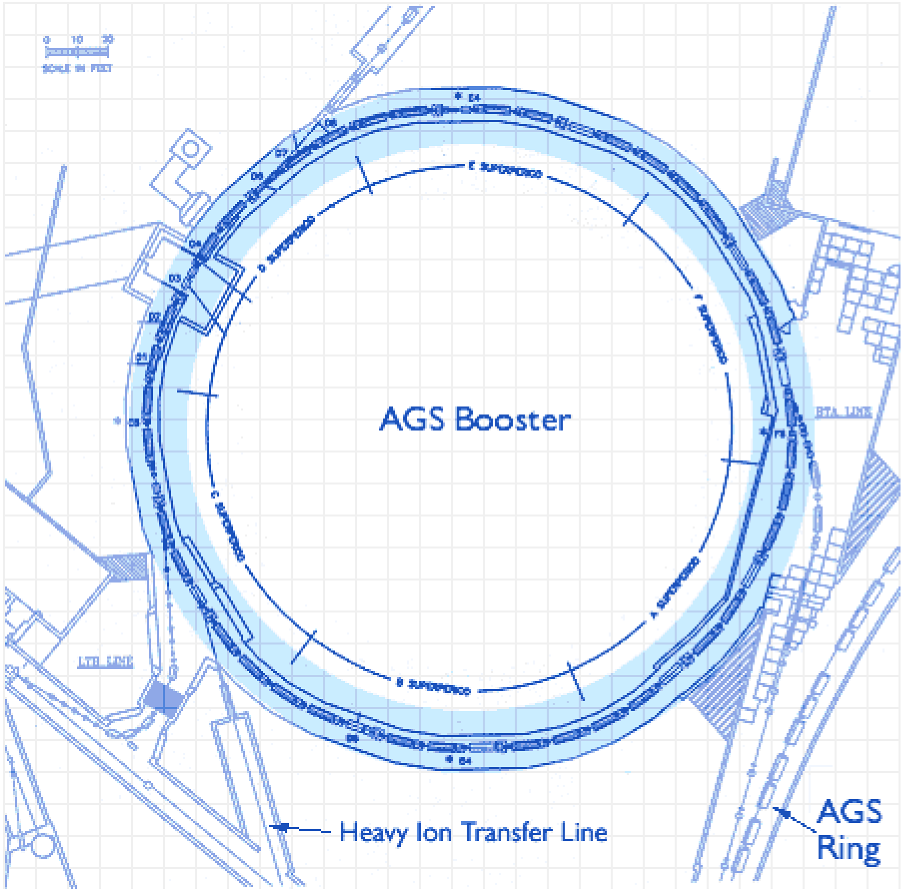


Construction of the Booster was begun in 1986 and completed in 1991. The Booster is a circular accelerator with a circumference of 600 feet, one fourth of the AGS, and is at the north corner of the AGS near the 200-MeV Linac. It is used to pre-accelerate particles entering the AGS ring, increasing the intensity of the particle beams generated by the AGS. A schematic of the Booster is shown in Figure 3.1.1.g. The schematic of the complex, Figure 3.1.1.a, illustrates how the Booster fits into the general arrangement. The Booster receives proton beams from the

Linac and heavy ion beams from the TVDG. The Booster injects higher energy beams through a fast extraction port and beam transport line into the AGS. The Booster increases the proton and polarized-proton flux in the AGS by a factor of four to six over that attainable by direct injection from Linac. Additionally, it allows higher mass ions to inject into the AGS, which is a key feature leading to the successful operation of RHIC. During routine operations, protons accelerate in the Booster at a flux of $6x10^{13}$ per second; that is, $l.5x10^{13}$ protons per pulse at 4 Hz, to energy of about 1.5 GeV. The pulse frequency can increase to 7.5 Hz, the proton energy can increase to about 2.1 GeV and the potential flux can be $1x10^{14}$ protons per second.

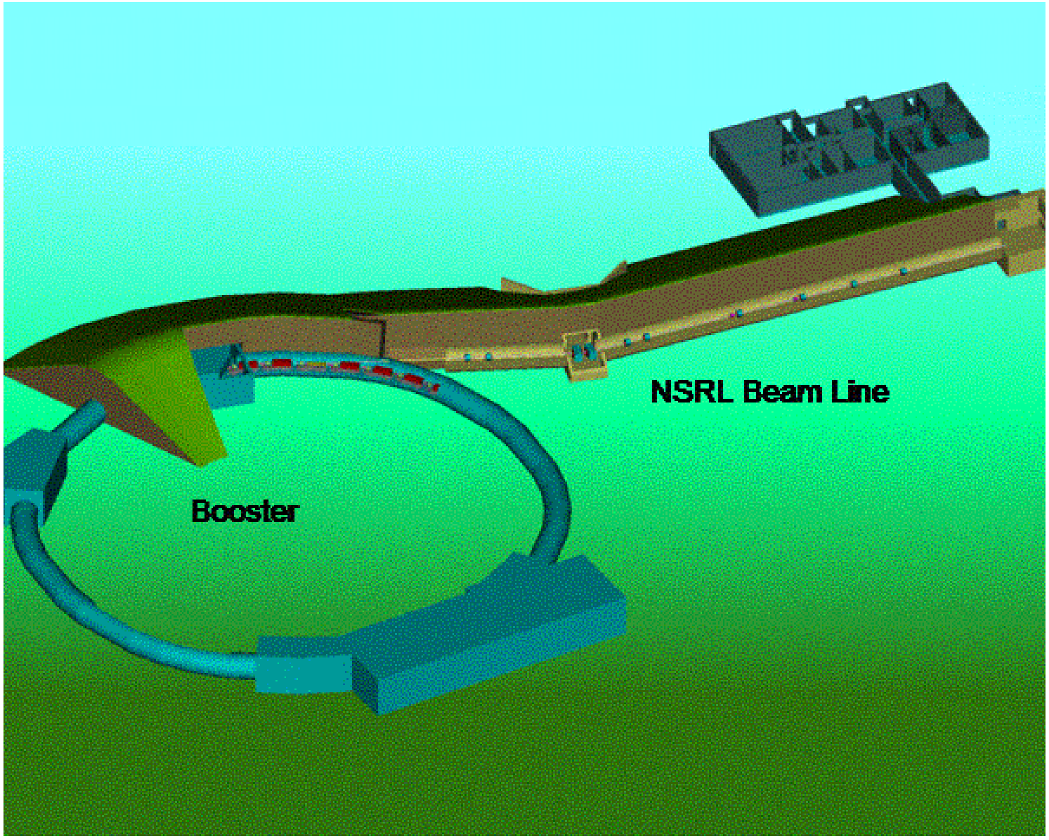
The Booster receives one pulse of heavy ions from the TVDG that it accelerates to energies between 0.3 and 1 GeV per nucleon with an acceleration cycle of about 1 second, before stripping the accelerated ions of most of the electrons and injection into the AGS. The flux and the energy of the beam depend on the mass and charge of the accelerated ion. The number of ions per second extends from $3x10^{11}$ for deuterons to $3x10^{9}$ for gold. In general, for heavy ions the total number of nucleons per second is about $6xl0^{11}$ at a maximum energy of about 1 GeV per nucleon.

Figure 3.1.1.g Schematic of the Booster



The NASA Space Radiation Laboratory (NSRL) is an experimental facility designed to take advantage of heavy-ion beams from the Booster accelerator. This facility is used for radiation biology studies, which are of great importance to the future of manned space flight. Radiation fields encountered in space may cause adverse health effects in humans. These effects are of special concern for prolonged space missions beyond the earth's protective magnetic field. Before such missions can be undertaken, a much more detailed understanding of these effects is needed to plan for the effective protection of astronauts. The Brookhaven AGS Booster is an ideal accelerator for these studies due to the good overlap between the available ions and energies with those encountered in space. Heavy-ions originate in the TVDG and travel through TtB to Booster for acceleration to high energies. Energetic heavy-ion beams are then delivered to a shielded NSRL target room where various specimens are exposed. Figure 3.1.1.h shows the layout of the NSRL facility with respect to the Booster.

Figure 3.1.1.h Schematic of NSRL Line, Target Room and Experimental Support Building



Of particular concern are the radiation effects due to the heavy ion components of galactic cosmic rays. There is considerable uncertainty regarding the risks associated with the high dose rates that would be encountered in long-duration space flight. Many studies with cells, tissue and animals are required to obtain adequate estimates of radiation-associated risks to humans in space. Such studies are conducted under controlled conditions utilizing ion beams that originate form the Tandem Van de Graff accelerator. The AGS Booster accelerates the TVDG ions to energies that match those encountered in space. The resulting energetic heavy ion beams are then delivered to a shielded NSRL target room where various specimens will be exposed. See Figures 3.1.1.i through 3.1.1.k that show different views of the facility.

Figure 3.1.1.i NSRL Facility off the AGS Booster

Figure 3.1.1.j NSRL Facility Plan View

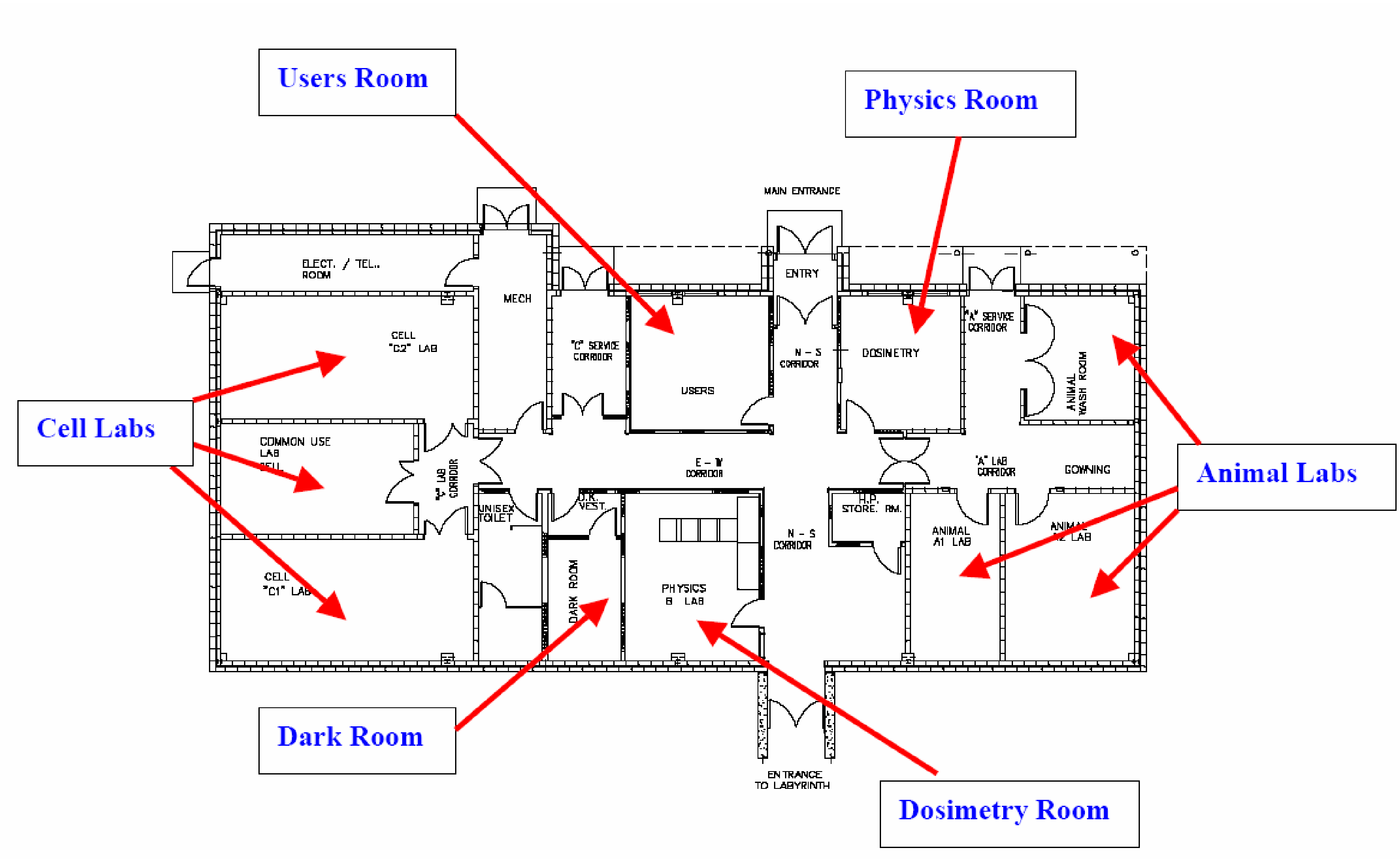
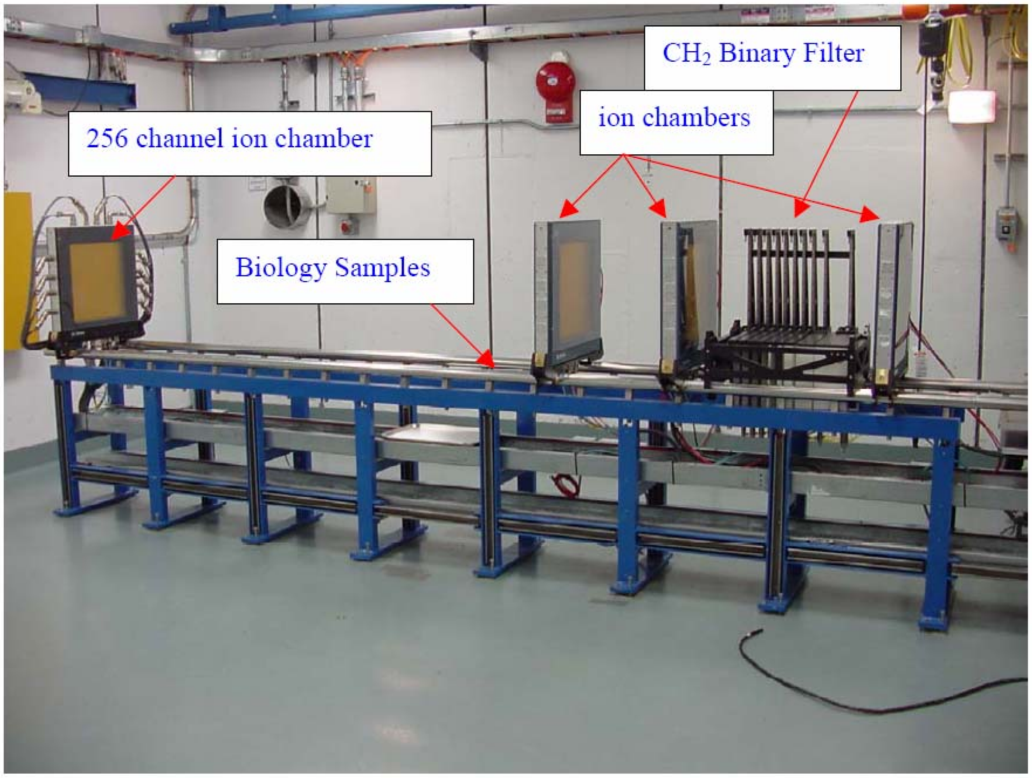


Figure 3.1.1.k NSRL Facility Target Room



Since 1960, the Alternating Gradient Synchrotron (AGS) has been one of the world's premiere particle accelerators, well known for the three Nobel Prizes won because of research performed with the particle beams. The AGS name is derived from the concept of alternating gradient focusing, in which the field gradients of the accelerator's 240 magnets are successively alternated inward and outward, permitting particles to be propelled and focused in both the horizontal and vertical plane at the same time. See Figure 3.1.1.l. The AGS is capable of accelerating $8x10^{13}$ protons (80 TP) with every pulse, and is available to accelerate heavy ions such as gold and iron. The AGS is used as an injector for the RHIC and as the final accelerator for high-intensity-proton fixed-target programs.

Figure 3.1.1.l AGS Magnet Enclosure

Figure 3.1.1.m shows the 5-acre experimental area, the g-2 experimental area and the AGS to RHIC line (AtR). More detail is shown in Figure 3.1.1.n. These areas take the output of the AGS and use it for experiments or for injection into RHIC. The Slow External Beam (SEB) exits the AGS via the F-10 extraction magnet. The SEB is focused by quadrupole magnets, and then it enters the switchyard. In the switchyard, electrostatic septa divide the beam into as many as four different paths, A-D. Each new beam is some fraction of the original intensity. Each of these beam lines are then confined and directed by arrays of quadrupole and dipole magnets to a production target and beam dump. The target, typically platinum metal with dimensions of a few inches, is the source of secondary particles of various species and a wide range of energies.

Secondary beam lines originate at these targets, gathering and admitting particles of the desired mass, charge and momentum using beam separators, and guiding the secondary beam, via magnets, to the experimental apparatus. This is usually a target where the interaction of interest takes place, surrounded by detectors, by means of which the interactions can be reconstructed. During operations, the radiation near the A through D beam lines or in the A through D target caves can be lethal. Each beam line is shielded with a combination of concrete blocks and steel. Occasionally some other materials may be used such as lead packing to seal interstices in the shielding. The total shielding inventory is 350,000 tons. The concrete shielding is generally loaded with ilmenite for a density of 3.5 g/cm^3, compared to normal concrete of 2.3 g/cm^3. Ilmenite is a naturally occurring iron titanium oxide. The steel is in the form of 10-ton buoy mooring blocks, steel armor plate up to 1.5 feet thick from scrapped naval vessels, and steel plate from other sources.

Figure 3.1.1.m AGS Experimental Areas and the AtR

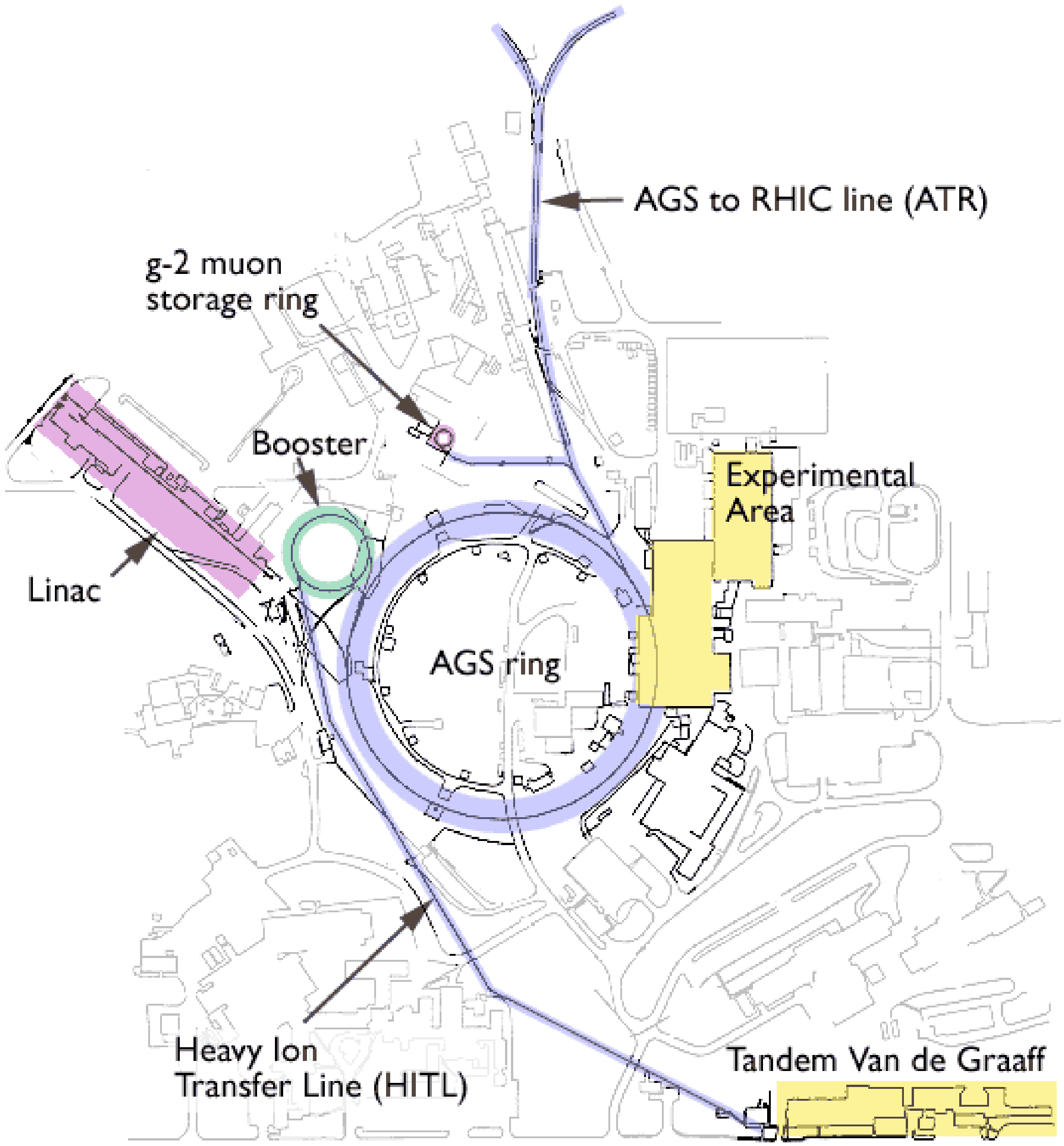
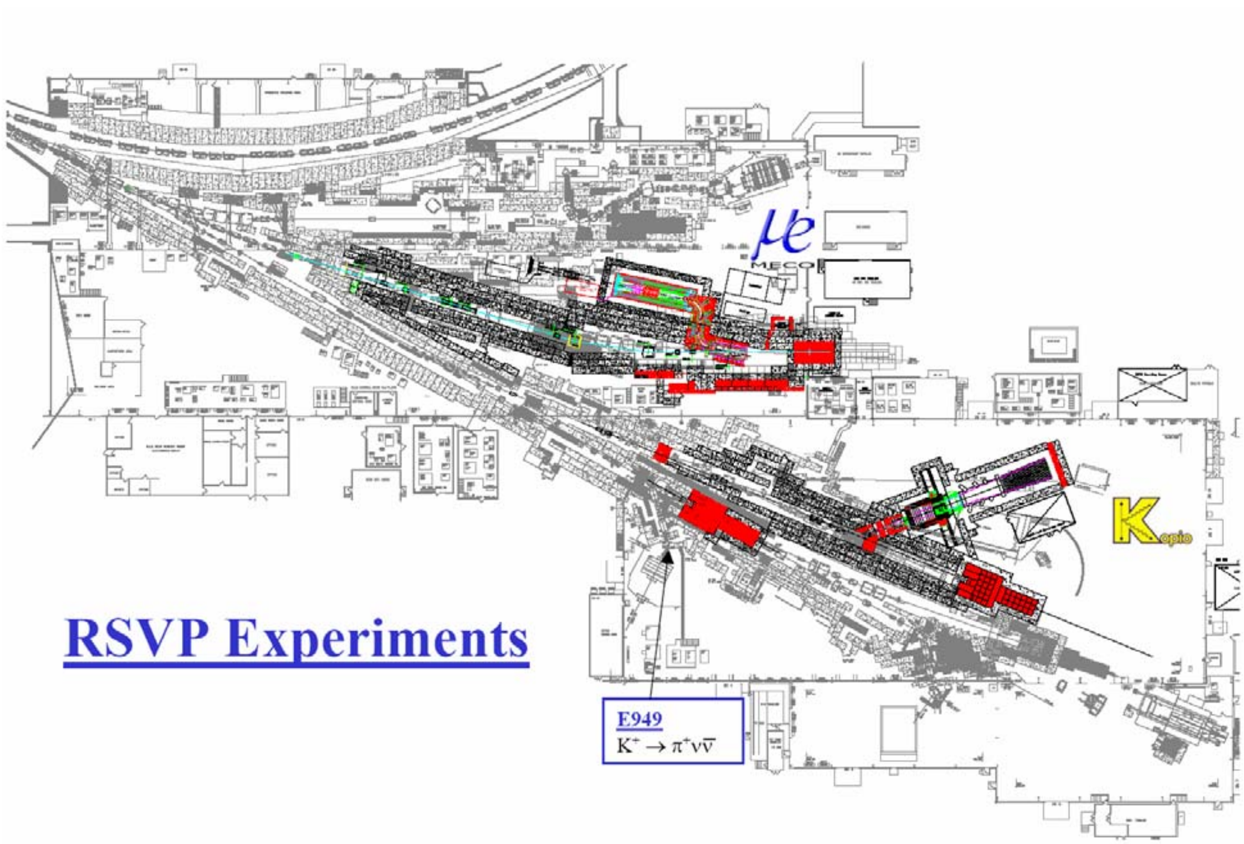


Figure 3.1.1.n Example of AGS Experimental Beam Lines



Experiments to be conducted in Building 912 include two experiments funded under the Rare Symmetry Violating Processes (RSVP) contract with the National Science Foundation. The RSVP program consists of the Muon to Electron Conversion (MECO) and the K Zero to Pi Zero (KOPIO) experiments. Together these experiments will be performed at the BNL Alternating Gradient Synchrotron (AGS) for 27 weeks per year.

The MECO and KOPIO experiments are examples of an approved class of experiments currently authorized by DOE for the AGS. Environmental, safety and health issues associated with this class of experiments were documented in the AGS Safety Analysis Report[4] and the AGS Environmental Assessment[5].

The scientific objective of the MECO experiment is to detect an example of the process of a muon converting to an electron in the field of a nucleus. The experiment is designed to detect a rate for this process as small as 2×10^{-17} times the rate for the process in which a muon is captured on a nucleus, changing the nuclear charge by one unit and emitting a neutrino. To date, no examples of a charged-lepton changing "flavor" have been observed, despite ever more sensitive searches being done since the 1940's. If the process is discovered, it will be evidence for fundamentally new physics outside the current understanding of elementary particles and their interactions, as described by the Standard Model. The expected sensitivity of the MECO experiment is approximately 10,000 times that of current experiments, and represents a tremendous discovery potential.

The proton beam used to produce the required muon beam will be sufficiently intense such that the design sensitivity of the experiment can be achieved in a reasonable running time. The beam will be pulsed in order to allow detecting the conversion process without backgrounds from uninteresting physics processes. The required time structure will be achieved by exploiting the time structure in the circulating AGS beam, which is defined by the accelerating RF structure. The beam will be extracted while it is still captured in two RF buckets separated by half the circumference of the AGS, resulting in a pulse train separated by 1.35 μsec. The intensity required is 4×10^{13} protons (40 TP) to the experiment during each AGS cycle, with one

[4] AGS Final Safety Analysis Report, AGS Department, Brookhaven National Laboratory, Associated Universities, Inc., Upton, New York 11973, February 27, 1991.

[5] Programmed Improvements Of The Alternating Gradient Synchrotron Complex At Brookhaven National Laboratory Upton, New York, Environmental Assessment, U. S. Department Of Energy, DOE/EA #0909, November 1993.

cycle per second. Increased bunch intensity and techniques to extract a bunched beam at the required 8 GeV operating energy will be developed to meet these requirements. New magnet systems within the AGS will be installed and new operating techniques developed to ensure that protons circulate only in the desired RF buckets.

The planned running time for MECO is a total of 4000 hours. Construction and engineering runs will occur in the years FY04 through FY09. Physics running will occur from FY10 through FY12. Total annual high-intensity running periods of 27 weeks will be shared with the KOPIO experiment.

A new AGS extraction line in Building 912 will be built for MECO. Tasks include removing existing equipment, refurbishing existing magnets and power supplies, and installing modified beam-line magnets, vacuum systems, beam-monitoring instruments, and shielding. These activities will not only allow the experiment to go forward, but they will have the added benefit of reducing radiation burden due to reduced beam losses and better shielding. A radio-frequency modulated magnet of new design will be developed to remove protons outside the desired pulses and allow monitoring of the performance of the AGS. Two new Lambertson magnets will be built and installed. A counter system will be built to measure the number of protons not in the desired pulses.

No new buildings or tunnels will be constructed for the MECO experiment. Existing accelerator components will be upgraded or replaced. Existing experimental areas in Building 912 will be modified and used for the primary beam line, target area, beam dump and secondary beam line.

A new proton target in the A line in Building 912 is required to produce the pions that will decay and produce the muon beam. The MECO target will either be a gold or platinum metal-target. The target will be cooled by water, liquid nitrogen or liquid helium. A 50-ton copper and tungsten shield will be built surrounding the target to protect the superconducting magnet, in which the target is installed, from the heat and radiation produced in the target. The shield will be supported off a cylindrical “strong-back” that will also serve as part of the vacuum vessel in which the muons are produced and transported.

A new, large bore, 5 T peak-field superconducting-magnet, which is the called the production solenoid, will be built to contain the pions and muons inside the shield and direct them into a magnetic transport region. A set of magnets consisting of sections of solenoids and toroids, which is called the transport solenoid, will be designed and built. The transport solenoid will serve to guide the beam of muons to the detector region in the evacuated bore of a new superconducting magnet, which is called the detector solenoid. The detector solenoid serves to capture electrons from the conversion process. The detector solenoid guides electrons to a region containing particle detectors that, together with the magnet, comprise a magnetic spectrometer.

It is noted that for all planned magnets at C-AD including the 5 T magnet planned for MECO, C-AD will conduct an initial hazard assessment on all parts of the system that produce static magnetic fields. As with magnet assessments that have occurred for existing magnets at C-AD, the MECO magnet assessments will consist of identifying the source, surveying the magnetic field strength and exposure potential, and evaluating the results based on the BNL exposure limits in the SBMS Subject Area, Static Magnetic Field Safety. The C-AD will implement all appropriate administrative and work control requirements indicated in the Subject Area for the MECO magnets.

Three collimators in the straight sections of the transport solenoid will serve to restrict passage to muons of the correct charge and momentum range. A thin beryllium window, situated in the second collimator, will absorb anti-protons.

Located in the detector solenoid are the muon stopping-target, the tracker, the calorimeter, the muon beam-dump and various absorbers. The stopping target consists of thin Al or Ti foils suspended by low-mass supports. Thin, low-Z cylinders and cones at large radii are required to shield the electron detectors from low-energy protons emitted by the stopping target following muon capture. Some of these are lithium-doped to absorb neutrons. A muon beam-dump will be required to contain muons that have neither stopped in the target nor decayed.

Conversion electrons will be detected in a tracking detector installed in the constant field region of the detector solenoid. The energy of electrons will be measured in a calorimeter downstream of the tracker. The calorimeter detector will be a high-density crystal detector. Crystal materials will be GSO, BGO or $PbWO_4$.

A cosmic ray shield will be constructed to limit the background from cosmic ray muons interacting in the stopping target. It will consist of both passive shielding and an active scintillator-based veto detector.

A new enclosure for the front-end electronics will be built close to the experiment. An existing exterior building will be refurbished for use as the counting house. A data acquisition system and online computing facility will be assembled to record MECO data and allow for data quality control. This will be supported by several workstations for data monitoring and tape handling hardware for data recording. A sketch of the experimental layout in Building 912 is shown in Figures 3.1.1.o and 3.1.1.p.

Figure 3.1.1.o MECO Experiment in Building 912, Floor Layout and Detector Layout

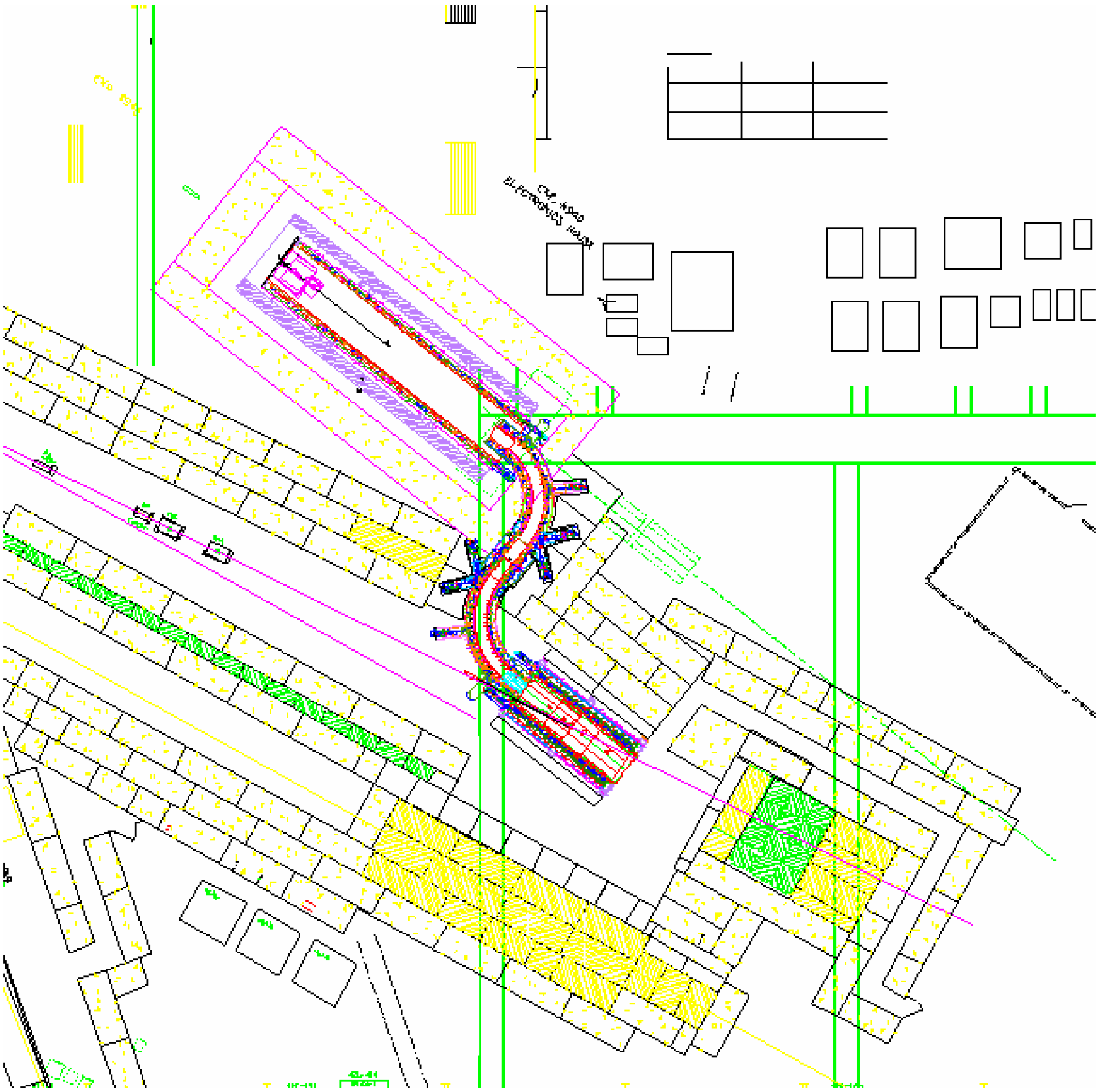
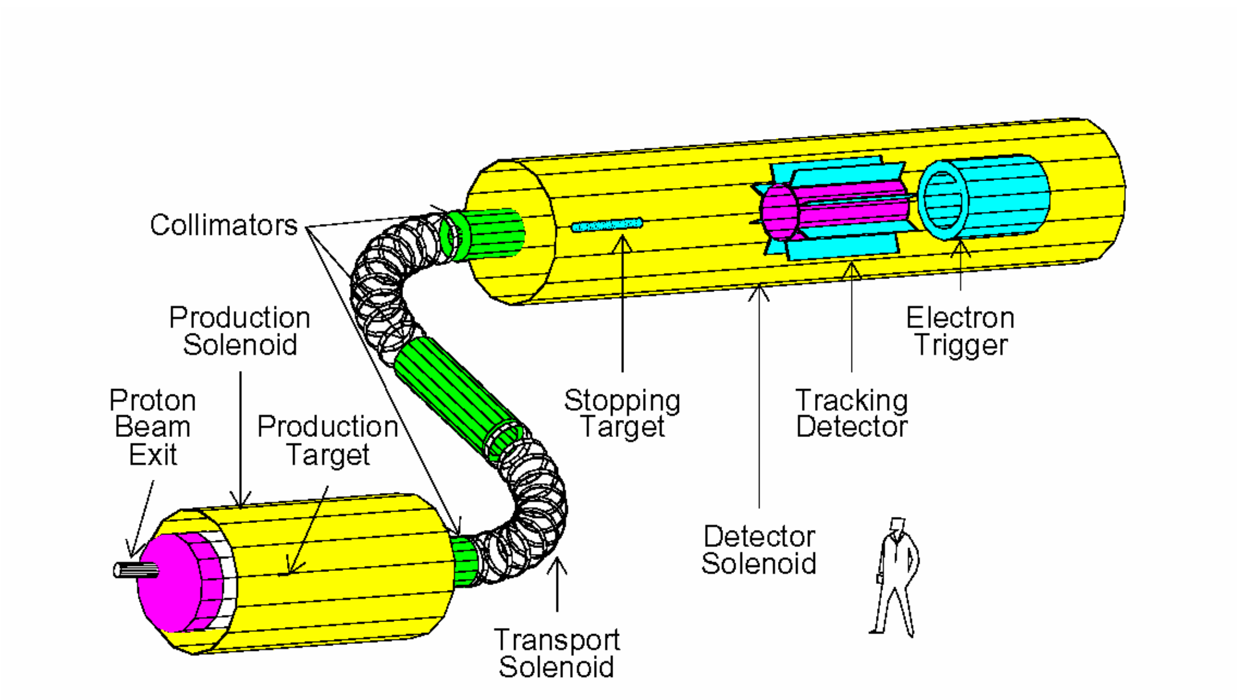


Figure 3.1.1.p MECO Solenoid Layout



Currently, CP violation[6] is recognized to be one of the most important outstanding issues in the study of elementary particle physics. The KOPIO component of the RSVP project

[6] CP violation is the violation of the combined conservation laws associated with charge conjugation (C) and parity (P) by the weak nuclear force, which is responsible for reactions such as the decay of atomic nuclei. Charge conjugation is a mathematical operation that transforms a particle into an antiparticle, for example, changing the sign of the charge. Charge conjugation implies that every charged particle has an oppositely charged antimatter counterpart, or antiparticle. The antiparticle of an electrically neutral particle may be identical to the particle, as in the case of the neutral pion, or it may be distinct, as with the antineutron. Parity, or space inversion, is the reflection in the origin of the space coordinates of a particle or particle system; i.e., the three space dimensions x, y, and z become, respectively, -x, -y, and -z. Stated more concretely, parity conservation means that left and right and up and down are indistinguishable in the sense that an atomic nucleus throws off decay products up as often as down and left as often as right.

Kaons are unstable and are artificially spawned in K-antiK pairs amidst high-energy collisions. Kaons are born courtesy of the strong nuclear force, but the rest of their short lives are under control of the weak force, which compels a sort of split personality: neither the K nor anti-K leads a life of its own. Instead, each transforms repeatedly into the other. A more practical way of viewing the matter is to suppose that the K and anti-K are each a combination of two other particles, a short-lived entity called K_S which usually decays to two pions (giving K_S a CP value of +1) and a longer-lived entity, K_L, which decays into three pions (giving K_L a CP value of -1). This bit of bookkeeping enshrined the idea that CP is conserved.

proposes a measurement of direct CP violation via the decay of a neutral kaon into a single neutral pion and a neutrino–antineutrino pair. The single most incisive measurement in the study of CP violation is that of the branching ratio for $K_L^0 \to \pi^0 \upsilon\overline{\upsilon}$. Using current estimates for Standard Model parameters, it is expected to lie in the range 3.1 +/- 1.3x10^{-11}.

The $K_L^0 \to \pi^0 \upsilon\overline{\upsilon}$ decay mode is unique, in that it is completely dominated by direct CP-violation and is entirely governed by short distance physics involving the top quark. Theoretical uncertainties are extremely small. Thus its measurement will provide the standard against which all other measurements of CP violation will be compared, and even small deviations from the expectation value derived from other Standard Model measurements will unambiguously signal the presence of new physics.

The KOPIO experiment in Building 912 will employ an intense low-energy, time structured secondary K_L^0 beam. This intense beam, with its special characteristics, will be provided via an intense proton beam extracted from the AGS. Building 912 will house the high-intensity proton beam extracted from AGS in a heavily shielded transport-line. Building 912 will also house the proton-beam target area, the secondary neutral-kaon beam-line and the detector.

The high-intensity proton beam will be created by micro bunching the AGS proton beam via two RF cavities.

For the KOPIO experiment, three upgrades to the AGS will be carried out by a collaboration of accelerator experts at BNL and TRIUMF. These upgrades are: 1) extracting a micro-bunched proton-beam, 2) increasing the proton intensity by a factor of 1.5 or more to 10^{14} protons (100 TP) per AGS cycle, and 3) modifying a primary proton beam-line in Building 912 to bring the intense micro-bunched beam to a new kaon production target. Part of this work involves upgrades to the Booster extraction kicker magnet and the AGS injection kicker magnet to deliver the increased kick strength required for proper 2.0 GeV operation of the Booster extraction/injection system.

After acceleration in the AGS, the primary proton beam required by KOPIO will be resonantly extracted at 25.5 GeV over 2.4 seconds with a micro-bunch structure of less than 200 ps rms. It is anticipated that the full AGS intensity of 10^{14} protons (100 TP) per AGS acceleration cycle of 4.7 seconds will be available.

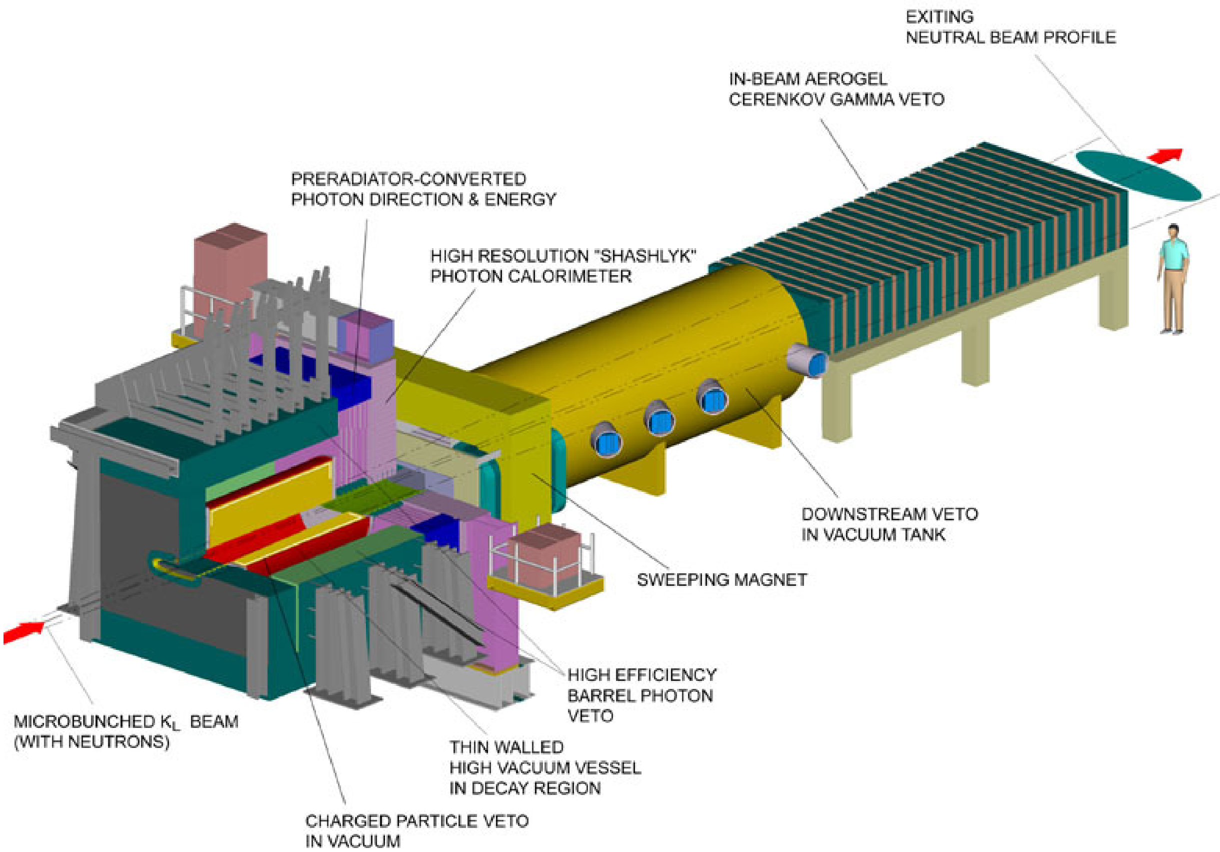
The planned running time for KOPIO is a total of 8000 hours. Construction and engineering runs will occur in the years FY04 through FY09. Physics running will occur from FY10 through FY14. In FY 10, 11 and 12 high-intensity running periods of 27 weeks will be shared with the KOPIO experiment. In FY 13 and 14, KOPIO will run without MECO.

No new buildings or tunnels will be constructed for the KOPIO experiment. Existing accelerator components will be upgraded or replaced with similar components that exist in the AGS and Booster. Existing experimental areas in Building 912 will be modified and used for the KOPIO primary beam-line, target area, beam dump and secondary beam line.

The micro-bunched beam extracted from AGS will be directed onto a B-line target to produce a neutral beam. The KOPIO target will be either gold or a platinum metal target cooled by water. These types of targets have been used successfully for many years at AGS. After the target, the beam-line elements necessary to collimate a neutral beam will be present. This includes a sweeper magnet to remove converted gamma rays and charged particles from the beam before entry into the KOPIO detector, and shielding to reduce unwanted backgrounds produced by the primary proton beam.

The detector will consists primarily of a vacuum system, a pre-radiator, a calorimeter system and a charged particle and photon veto systems (see Figure 3.1.1.q). The vacuum will consist of a high-vacuum segment, which will contain the decay events of interest, and a low-vacuum system, which will minimize downstream interactions. The pre-radiator system will consist of 32 modules constructed of dual-coordinate drift chambers, scintillators and layers of lead and copper. The pre-radiator will convert gamma rays and measure their directions. The calorimeter system will consist of lead-scintillator modules to measure energy. The photon veto will be a lead-scintillator sandwich that will be read out by wavelength-shifting fibers and phototubes. The charged particle veto will eliminate charged particles with very high efficiency, and the beam catcher will be a veto system used directly in the beam to detect and veto remaining photons.

Figure 3.1.1.q Relative Size of KOPIO Experimental Layout in Building 912



Existing utilities and roads in and around Building 912 will be used to support the MECO and KOPIO experiments. Existing power supply/utility buildings will be used. These buildings will house power distribution systems, power supplies, water pumping systems, instrumentation and controls for the MECO and KOPIO beam lines.

Electrical power is currently distributed around the site at 13.8 kV. Existing unit substations will transform the power into convenient voltages, typically 480 and 208/120 volts. Electrical power is divided into two major categories: conventional and experimental.

Conventional power encompasses building power for lighting and convenience power for heating, ventilation, air conditioning and miscellaneous equipment. Although there are no safety critical power needs, emergency power is be provided as required for smooth operations. Experimental power to AGS experimental areas feeds all the power supplies for magnets and associated equipment such as cooling-water pumps and cooling towers. All electric power distribution designs follow the requirements of the National Electrical Code and industry standards.

The cooling water systems for AGS experiments use cooling towers for primary heat rejection. The cooling water systems for tritiated water lines in AGS experiments are isolated, closed-loop cooling systems with heat exchangers. All tritiated water systems for AGS experiments comply with Suffolk County Article 12 requirements.

A shielded storage area is provided for radioactive component storage and repair of equipment used for AGS experiments. Modular concrete and steel shielding provides radiation shielding. Access to the proton target areas for installation and removal of the components is accomplished by removing the modular shielding. The design of radiological areas incorporates the as-low-as-reasonably-achievable (ALARA) radiation protection principles.

The un-interacted proton beams from KOPIO and MECO will exit to steel and concrete beam-dumps, which will be located inside Building 912.

The soil beneath the target areas and beam-dump areas is covered by Building 912. These activated soil areas are protected by a building roof, and a concrete floor with a water-resistant lining. The water-resistant lining is placed on the surface of the concrete floor over the target and beam-dump areas and it adds an additional barrier to prevent water infiltration into these soil areas.

The detector assemblies for KOPIO and MECO will utilize non-hazardous material configurations such as plastic or glass-type scintillator detectors with steel as the absorber materials.

The shielding policy for the KOPIO and MECO experiments is the same as that for the rest of the Collider-Accelerator facilities. Specifically, the Collider-Accelerator Department's Radiation Safety Committee reviews facility-shielding configurations to assure that the shielding has been designed to:

- prevent contamination of the ground water
- limit annual site-boundary dose equivalent to less than 5 mrem
- limit annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities to less than 25 mrem
- limit dose equivalent to any area where access is not controlled to less than 20 mrem during a fault event
- limit the dose equivalent rate to radiation-workers in continuously occupied locations to ALARA but in no case would it be greater than 0.5 mrem in one hour or 20 mrem in one week
- limit the annual dose equivalent to radiation workers where occupancy is not continuous to ALARA, but in no case would it exceed 1000 mrem.

In addition to review and approval by the Radiation Safety Committee, final shield drawings are approved by the Radiation Safety Committee Chair or the C-AD ESHQ Associate

Chair. Shield drawings are verified by comparing the drawing to the actual configuration. Radiation surveys and fault studies are conducted after the shield has been constructed in order to verify the adequacy of the shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed and controlled by Collider-Accelerator Department procedures.

In addition to fixed-target experiments in Building 912, a fast proton beam may be extracted to perform fixed-target experiments in Building 919 and in the U line in Building 927. The Fast External Beam (FEB) exits the AGS via the H-10 extraction magnet. The fast beam enters the V line, which leads to the g-2 experiment, or it is directed to the U line, which is roughly parallel to the AGS to RHIC (AtR) transfer line, where additional fast beam experiments are performed. The heart of the g-2 experiment is a storage ring 21-feet in radius with superconducting coils providing a magnetic field of 1.47 T uniform to 1 part per million (ppm) over a toroidal volume 3.5 inches in minor diameter. Experiments in the U line are typical fixed target type surrounded by detectors, by means of which the interactions can be reconstructed.

The AtR line contains the aforementioned U and V lines plus the W, X and Y lines leading into RHIC. Beam bunches extracted from the AGS must pass through the AtR to get to the Collider. The AtR begins downstream of AGS fast extraction which comprises the G-10 extraction kicker magnet and H-10 extraction magnet. Before exiting the AGS, the beam undergoes a 4.25-inch bend through two dipole magnets accompanied by three quadrupoles for focusing. Bunches then traverse the U- Line. A stripping station is located in the U line where the last two electrons are removed from the not fully stripped heaviest ion species. The stripper is retracted when it is not needed. The first section of the AtR shares operation with U and V lines. The next section of the AtR, the W-Line, uses magnets to deflect the beam both horizontally and vertically. This deflection capability in the U-Line provides for flexibility in the choice of focusing parameters at the entrance of RHIC. It ensures symmetric behavior of the beam into the beam transfer branches, which are known as the X and Y arcs, which lead into the two rings in the RHIC tunnel. In AtR, a switching magnet is maintained to ensure a safe-off configuration whenever it is necessary to prevent transport of beam into the X or Y arcs. With the switching magnet de-energized, the beam will stop in a marble encased steel dump at the end of the W-Line, just before the X and Y arcs.

It is noted that the term ‘beam stop’ indicates the primary beam is stopped. Stops are used to prevent primary beam from traveling forward, and are used infrequently. Secondary particles created from stopping the primary beam at beam stops can and do move forward in the beam line. The term ‘beam dump’ is used to indicate a repository for both a primary beam and any secondary particles that contain most of the primary beam’s energy. Typical beam stops are small diameter metal objects several mean free paths in length that are sometimes cooled by water, whereas beam dumps are massive structures of concrete and steel sometimes as large as 12 feet x 12 feet x 50 feet.

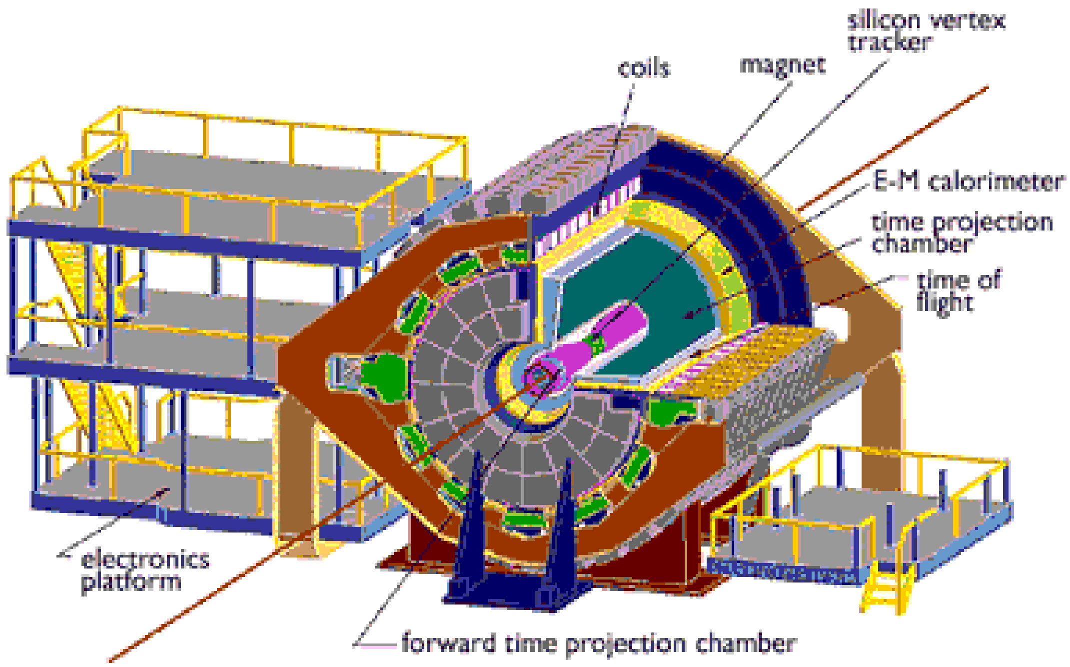
The RHIC machine itself is enclosed in a tunnel, 12 feet under the ground. Inside the two tubes shown in Figure 3.1.1.r, ion bunches travel around RHIC's 2.4-mile ring in opposite directions. The ion beams inside the two tubes are referred to as the yellow and blue beams. Each collider ring is made of hundreds of magnets. RHIC's magnets look different from those at the AGS because RHIC magnets are superconducting, using niobium titanium wire to carry the electrical current. Each magnet cylinder contains the steel magnet plus the cryogenic and electrical distribution systems. Like AGS, ion beams travel in a vacuum pipe in the middle. However, unlike AGS, super-insulation is used to wrap each magnet inside a cylinder, and beneath the insulation layers, super-cold helium is circulated to ensure temperatures stay at 4.5^{o} K. Like Booster and AGS, RHIC uses an RF system to give the circulating particles more energy.

Figure 3.1.1.r RHIC Tunnel Enclosure

RHIC's 2.4-mile ring has six intersection points where its two rings of accelerating magnets cross, allowing the particle beams to collide. The collisions produce the fleeting signals that, when captured by one of RHIC's experimental detectors, provide physicists with information about the most fundamental workings of nature. If RHIC's ring is thought of as a clock face, then the four current experiments are at 6 o'clock (STAR), 8 o'clock (PHENIX), 10 o'clock (PHOBOS) and 2 o'clock (BRAHMS). Additionally, there is a polarized-hydrogen-gas target (JET) in RHIC and it is used for elastic scattering measurements when polarized proton beams are circulating. The JET target is located at the 12 o'clock intersection point and the yellow and blue beams in RHIC are separated by ~10 mm instead of colliding. Only one beam at the time interacts with the JET target.

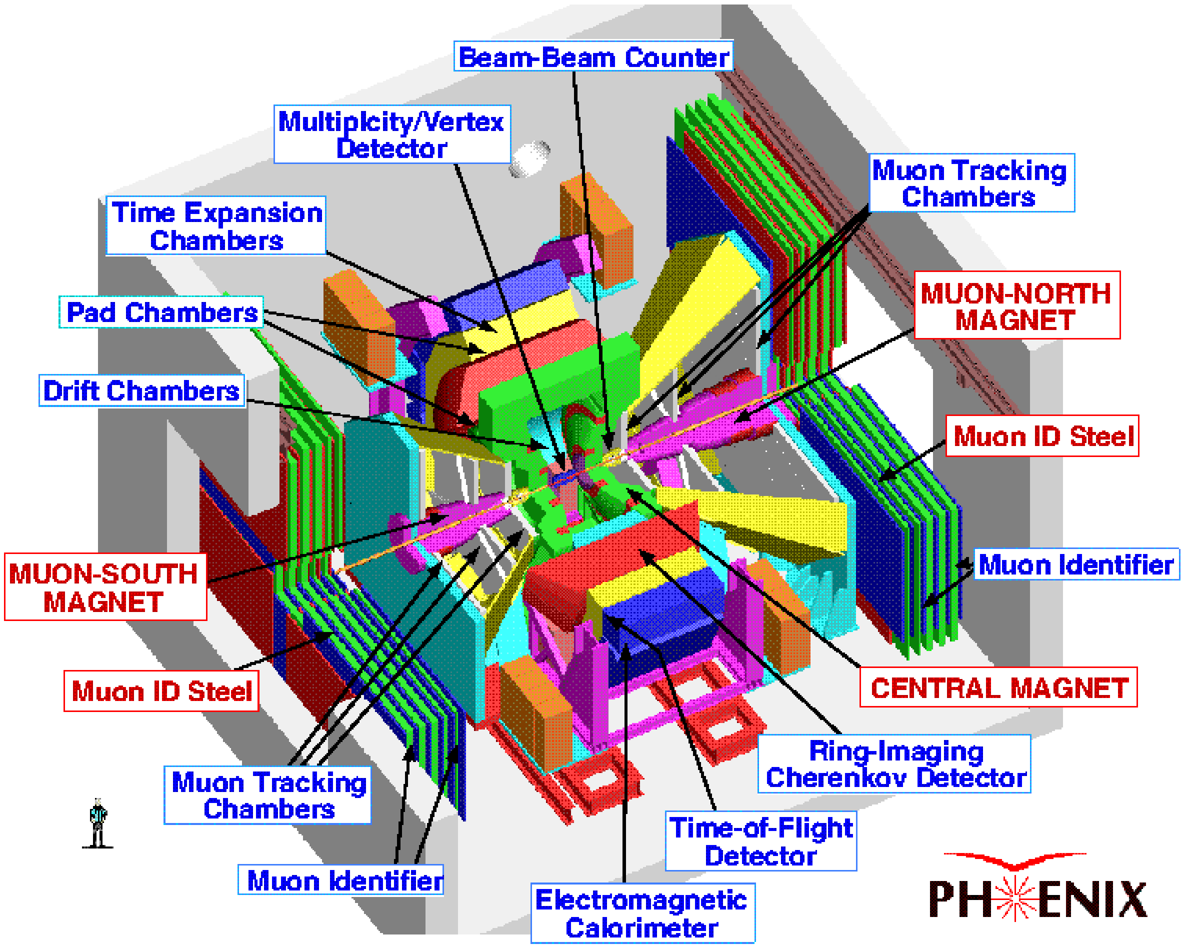
An example of a large experiment at RHIC is the Solenoidal Tracker at RHIC (STAR). This detector specializes in tracking the thousands of particles produced by each ion collision at RHIC. Weighing 1,200 tons and as large as a house, note ladder in image at left in Figure 3.1.1.s, STAR is a massive detector. It is used to search for signatures of the form of matter that RHIC was designed to create, which is the quark-gluon plasma. It is also used to investigate the behavior of matter at high energy densities by making measurements over a large area.

Figure 3.1.1.s STAR-Layout at a RHIC Intersection Region



Another example of a large experiment is the PHENIX experiment at RHIC. The PHENIX experiment aims at a broad investigation of many possible signatures of the Quark Gluon Plasma (QGP). It has a primary emphasis on leptons, both electrons and muons, as well as photons and hadrons. This is accomplished by an array of four spectrometer arms surrounding inner detectors that provide vertex, multiplicity and trigger information. PHENIX can simultaneously explore a wide variety of phenomena as a function of a few global variables. If the QGP exists it should manifest itself in several of these channels, and the appearance of multiple signals will underscore the reality of the phenomena being observed. Because of this broad approach, PHENIX is arguably one of the most complex detectors ever conceived (see Figure 3.1.1.t), encompassing 11 different detector technologies, as well as a sophisticated trigger and state of the art data acquisition system. The detector is comprised of two almost identical large aperture particle spectrometers at 90 degrees to the beam line, two almost identical spectrometers and identification systems for muon analysis along the beam lines, and two inner detectors. The core of PHENIX is provided by three large magnets. The collision point is surrounded by a central magnet (CM) which provides an approximately axial field. Along the beam line, two muon magnets (MM North and MM South) provide radial fields for analysis of muon tracks. These unique magnets have coils that excite a central conical steel piston. The magnetic flux is returned through a steel lampshade providing a radial field in the interior volume where tracking detectors are placed.

Figure 3.1.1.t PHENIX Experiment at RHIC



There are two electron accelerator systems planned for the 4 o'clock region of the RHIC ring, one system per ring, and they will be used to cool the ion beam in RHIC. An energy recovery Linac will be used to generate a 50-MeV electron beam that reduces the transverse energy of the circulating ions. Energy transfer between the 'cold' electron beam and the 'hot' ion beam will take place in a uniform solenoidal magnetic field in order to maintain particle alignment. Each electron accelerator consists of a photocathode RF electron gun “photo injector,” a laser system to drive the photocathode, a superconducting Linac section, an electron-beam-transport consisting of an evacuated tube and various magnets and a beam-dump, and a large superconducting solenoid. The copper photo injector generates an electron beam of about 500 mA at 1.5 MeV or 100 mA at an energy of 2.5-MeV. The superconducting Linac energy reaches up to 50 MeV. An energy recovery of the Linac is used, so that the electrons are dumped at the photo injector energy. As plans for these electron-cooling accelerators develop, an update to this Safety Analysis Document will be developed.

3.1.2.Characterization of the Support Facilities

Accelerator operations in the Department require the following supporting facilities and supporting equipment:

- 6.2 miles of vacuum pipe
- 24 miles of cable tray
- several thousand electro-magnets
- compressors for the cryogenics systems
- 120+ buildings
- 45 electrical substations
- dozens of cooling towers
- 1.2 million ft^2 of office and laboratory space
- 1000 acres of land

- Several million tons of earth shielding
- 350,000 tons of concrete and iron shielding

Accelerator operations also require the following support: cooling operations, beam line assembly and disassembly, cryogenic system maintenance, electronics assembly operations, magnet cleaning operations, metal cleaning operations, plating operations, machine-shop operations and vacuum system operations.

Magnets are used to contain, bend, split and focus the beam and are located within the walls of the accelerator ring as well as within sections of the beam lines. There are numerous magnets maintained by the C-A Department, which use large amounts of electricity to create a strong magnetic field. Electrical cables attached to the magnets carry the electricity from the power supplies and rectifiers to the magnets. Due to the large amount of heat generated by the electricity that encounters resistance during use, a cooling water system is utilized to prevent the magnet from overheating.

The RHIC uses superconducting magnets to bend and focus the beam. The magnets in RHIC are cooled to 4.5 ^{0}K using supercritical helium gas. It is noted that helium will remain liquid at 1 atmosphere pressure provided the temperature does not rise above 4.2 ^{0}K. If the RHIC magnets are cooled with liquid helium and a high pulse of heat ensues in their operation, most of the helium must be vented to avoid large overpressures. To avoid this, the magnets operate with pumped supercritical helium gas, just above the critical temperature, which retains a large measure of the heat transfer properties of liquid helium, without the risk of overpressure. At cryogenic temperature of 4.5 ^{0}K, the magnets acquire superconducting properties, thereby greatly reducing the amount of electricity, which must be supplied to generate the magnetic field, and greatly reducing the amount of heat generated that must be removed to prevent the magnet from overheating.

The cryogenic system located in Buildings 1005R (Refrigerator Building) and 1005H (Compressor Building) supplies supercritical helium gas to cool the Collider magnets. The ring cryogenic system typically operates continuously up to 36 weeks per year. In simplified terms, the cryogenic systems operate as follows: gaseous helium is compressed and routed through carbon purifiers to remove any contaminants. The helium is then cooled through a heat exchanger and turbine expander system and both liquid helium and supercritical helium are produced. Vacuum pumps are used to evacuate the enclosed space surrounding the cryogenic equipment and piping to prevent convective heat transfer. Maintenance operations include the routine replacement of vacuum pump oil and o-rings, gaskets and seals, as required.

Screw-type compressors are utilized to compress the gaseous helium for subsequent expansion into liquid and supercritical helium. Oil for the compressors in Building 1005H is supplied from one 300-gallon oil tank, which is located inside the building.

In addition to the compressors used for compressing helium, the cryogenic system includes several compressors that are used as pumps and utility compressors. Each of the valve box locations has a utility compressor. The compressed helium supplied to the valve boxes is required to be dry and oil free. Thus, each is equipped with a dryer and oil mist and oil/water separator. These compressors do not hold large quantities of oil.

Other cryogenic system equipment includes the following: rotoflow control skids used to adjust the speed on the turbine expanders; heat exchangers used to cool the oil from the compressors; and, an oil purifying system is used to purify compressor oil in Building 1005H.

When helium gas flows through the screw compressors, some oil becomes entrained in the helium and must be removed prior to the helium entering the heat exchangers. From the compressor the helium passes through a series of coalescers, which are coarse filters, mist eliminators, which are fine filters, and molecular sieves, which is activated charcoal often referred to as charcoal beds.

During construction operations, magnets are removed from storage or an inactive beam line and mounted within their designated location. Cooling lines and electrical cables are attached to the magnets, run beneath the shielding walls where required and attached to the equipment. During disassembly operations, the magnets are placed in storage for future use. Cooling lines are disconnected from the cooling manifold and electrical cables are disconnected from the rectifiers and power supplies. Any worn or broken magnet coils, wiring or cooling manifolds are removed from the magnets and replaced with new parts or parts from storage. All worn or broken parts are surveyed for radioactivity to ensure proper disposal. Magnets, which may have become activated during use, depending on the location of the magnet, are placed in a Radioactive Materials Area, covered with shielding and left to "cool-off," which is also termed decay-in-storage. If a magnet component is to be discarded, then it is disposed of as radioactive waste.

There are many cooling water systems associated with the RHIC, AGS, Linac, Booster, NSRL and AGS primary/experimental beam lines. These systems are used for cooling magnets, electrical equipment, RF cavities, vacuum pumps, beam targets, compressors, buildings and various types of equipment. Equipment used to transfer or reject heat from the cooling water includes heat exchangers, chillers, evaporative coolers and cooling towers. The cooling water systems include closed loop, open loop and once through systems. As required, cooling water is supplied from the BNL potable water system and, if within acceptable limits, is discharged to the AGS and RHIC recharge basins, storm system or BNL sanitary system. Some cooling water systems have become activated due to interaction with the beam or radiation from the beam.

Radioactive water drained or collected from the various radioactive cooling water systems is transferred to one of three 7,000-gallon tanker trailers. These tankers, usually located at Building 974 can be moved by truck throughout the site to facilitate transferring of wastewater. The tankers are constructed of stainless steel and are parked within secondary containments when not being used to transfer water.

Steam or electric heat can be supplied to the tankers to slowly heat the wastewater and evaporate it. This wastewater treatment process has been reviewed against DOE Order 435.1, Radioactive Waste Management, and the process meets requirements. The vapor contains tritium from the activated cooling water systems. The emissions from the process have been assessed against NESHAPS requirements and radiation dose rates are well below levels that require continuous monitoring. Tanker water may be reused/recycled or evaporated. In recent years, as much as 20,000 gallons per year have been re-cycled while only a few thousand gallons per year were evaporated.

The beam lines are composed of aluminum or steel pipes through which the beam travels. The pipes along the primary beam lines and near the targets are activated by the beam, but those located along the secondary or experimental beam lines typically are not because the beam has less energy after hitting the targets. The experimental beam lines utilize magnets for containing and focusing the beam. During construction operations, the pipes are removed from storage or new piping is purchased and welded together to create a path to the experiment station. During disassembly operations, the sections of pipe are cut and stored in the C-A warehouse for future use following a “cooling off” period, if activated.

Various types of materials are welded during beam-line assembly operations including vacuum flanges, aluminum and stainless steel pipe, and magnet stands. In addition to welding, soldering is performed utilizing soft solder (tin/lead) and silver solder to connect electrical wires to various pieces of equipment.

The beam lines are constructed and disassembled, as required, in order to accommodate the particular accelerator or experiment. Beam lines typically consist of the beam line and magnets; electrical equipment and vacuum pumps; magnet cooling system; and concrete and metal shielding. Unless damaged beyond repair, equipment and material are reused by the C-A Department for the construction of new beam lines.

Magnets are periodically cleaned while in place to remove particulates such as scale and/or silt, which build-up in the piping bends and turns of the magnet cooling system. Particulates which build-up within the magnet cooling system can block cooling pipes and cause the magnet to overheat. The three techniques utilized for cleaning fouled or blocked magnets, in the order used, are backwashing, flushing with compressed nitrogen and flushing with an acid solution.

During operation with beam, large amounts of radiation are produced whenever the beam is split, collimated or stopped. Shielding is utilized to reduce or eliminate personnel and equipment exposure to radiation generated during beam operation. Shielding is required for the primary beam lines and target areas; however, it may not be required for the experimental beam lines (see Table 3.2.2.1, General Guideline for C-A Radiation Access Control System).

Shielding for the beam lines is typically reused from previous beam lines. Shielding is constructed of concrete block, steel plates and less frequently, lead bricks or other materials. The shape, thickness and placement of the shielding are determined for each application. Shielding is stacked on the floor around the beam line creating what is referred to as a "tunnel." Magnets, electrical cables, cooling water lines, vacuums pumps and the beam line are located within the tunnel. The remainder of the support equipment is located outside the tunnel and is therefore shielded from radiation produced by the beam. Cooling lines and electrical cables run in trenches beneath the tunnel walls to connect equipment located outside the tunnel. Shielding is offset stacked so that the gaps between the materials do not align to create a path through which radiation could pass. Large overhead cranes located within the building are utilized to move the shielding. These cranes are maintained by the BNL Plant Engineering (PE) Division.

Concrete blocks used for shielding were historically fabricated off-site utilizing "heavy" concrete. "Heavy" concrete is typically made of ilmenite-loaded concrete. Ilmenite is a natural substance. It is a mineral ($FeTiO_2$) with a high iron-content. Some new concrete shielding is fabricated on-site utilizing "light" 3,000-psi concrete. The shapes of the concrete blocks are designed for a particular location and use. When not needed immediately for shielding, the concrete blocks are stored in the outdoor Block Yard located north of Building 912 for reuse later.

Large steel plates and, less frequently, lead or tungsten bricks are utilized to provide shielding for the beam lines. While steel plates are utilized throughout, the lead or tungsten bricks are used as a collimator, which is a device for reducing the beam size by eliminating beam halo. These materials are stored for future use when not immediately needed for shielding. The steel plates are stored in the outdoor Steel Yard located adjacent to the Block Yard north of Building 912 and the lead bricks are stored within a small building located to east of Building 912 for reuse at a later date. Building 974 may also be used for material storage.

The beam line electrical systems consist of power supplies and rectifiers, which supply electricity to the magnets. The equipment is located outside of the shielding and is wired to the magnets within the shielding tunnel.

Rectifiers are utilized to convert incoming alternating current (AC) to direct current (DC), which is used to power the magnets. There are approximately 400 rectifiers used by the AGS alone. Some rectifiers contain capacitors that utilize dielectric oil containing polychlorinated biphenyls (PCBs). All rectifiers containing PCBs have been inventoried and are affixed with large warning labels stating, “Caution Contains PCBs.” All rectifiers, including those containing PCB capacitors, are checked for leaks prior to each run.

Devices referred to as “beam separators” require a significantly larger amount of electricity to operate and therefore use much larger power supplies. The high-voltage beam-separator power supplies contain approximately 500 gallons of dielectric oil. Due to the expansion of the oil from the heat being dissipated, large surge tanks are attached to the power supplies to accommodate the oil’s change in volume. The power supplies and surge tanks are located within secondary containment.

Vacuum pumps are utilized to evacuate the beam lines to prevent collisions of the beam with air molecules. The pumps are small capacity and typically contain less than 5 gallons of vacuum pump oil. Pumps located near floor drains are placed within secondary containment. Approximately half of the vacuums pumps are located within the beam line tunnels and half are located outside the tunnels depending on the available space. Periodically, vacuum pumps are brought into Building 911A, and to a lesser extent into Building 820, to be serviced. Servicing includes replacing equipment fluids and worn parts, and inspecting the equipment to ensure that it is operating properly. The Vacuum Lab area in 911A is also used for the enamalization of flanges. A parts steam cleaner is available in Building 820 to clean and remove dust from parts in storage.

The staff shops support the fabrication and maintenance of equipment, supplies and components used throughout the C-A Department. These shops consist of various machines used for the small-scale fabrication, assembly, maintenance, repair, and cleaning of metal and fiberglass equipment and parts. The machines used in the Staff Shops include milling machines, lathes, drill presses, band saws, grinders, shears, sanders, punches, breaks, benders, grit blasters and parts cleaners. Magnet refurbishment work is also conducted in Building 922, where worn or damaged magnet components are repaired or replaced. This operation involves soldering, metal cleaning, silver plating, coil maintenance, and cooling water hose and fitting repair.

Electronics assembly operations are conducted in Buildings 911A, 911C, 919B and 923 and are associated with the fabrication and operation of Collider-Accelerator support systems. Electronic assembly refers to the installation and interconnection of wires, mechanical connectors and electronic components onto printed circuit boards and within a piece of equipment.

Experiment stations are located at the end of the experimental beam lines or at interaction regions in the accelerators, and are constructed, maintained and disassembled by the investigators with assistance provided by the C-A Department. Experiment stations include detectors, instrumentation, data acquisition equipment and support systems. Experiment stations may also include magnets, power supplies to supply current to the magnet, PLC based controls and monitoring, buss systems to bring the power to the coils, and some experiments have hydraulic based moving systems for the magnets. The C-A Department typically assists the investigators with rigging and moving large pieces of equipment and shielding where required.

Typical gases used in particle detectors are nitrogen, carbon dioxide, helium, neon, xenon, argon, methane, ethane, isobutene, tetrafluoromethane and P-10. Nitrogen and carbon dioxide are stored as cryogenic liquids. Compressed inert gases such as carbon tetraflouride, helium, neon and xenon are stored in cylinders. Separately the liquefied hydrocarbons, ethane, methane and isobutane, are stored in cylinders. The C-A Department assists in the installation and disassembly of gas storage areas, gas mixing houses and gas piping to particle detectors.

Wherever large particle detectors reside, there are a variety of safety systems. The main safety systems include fire, smoke, flammable gas and oxygen deficiency (ODH) monitors. Some of these safety systems exist at up to three levels. The experimental areas are also serviced by HVAC systems that provide a continual fresh-air exchange, averting rising concentrations of leaked and locally vented gases. Emergency vent systems also exist and produce a high flow to dilute an airborne hazard. They are used to vent sudden, large gas leaks or smoke or may also be activated by the ODH alarm. The C-A Department assists in the installation, modification, replacement and disassembly of these safety systems.

3.2.Design Criteria and As-Built Characteristics

3.2.1.Design Criteria and As-Built Characteristics for Beam Instrumentation Systems

The purpose of the Beam Instrumentation Systems (BIS) is to minimize beam loss and to help provide the required beam on target. The C-A Department management has required that inadvertent beam loss occur at levels that are as low as reasonably achievable with operational, economic and community factors taken into account. As a minimum, the C-A Department has the following design criteria that the builders and managers of BIS must meet:

- set threshold acceleration, extraction and transport loss limits that activate alarms
- formally, approve changes to acceleration, extraction and transport loss limits as operations evolve
- identify appropriate instrumentation for measurement of the losses, and ensure measurements are reviewed at appropriate intervals in order to validate loss assumptions
- ensure alarm threshold values used by operations personnel are incorporated into the appropriate computerized controls programs
- ensure that written operations procedures contain loss limits
- ensure response by operators to alarms is clearly written in procedures; loss problems must be corrected within minutes; otherwise, operators must reduce the beam intensity to the affected area (for example, see OPM 6.1.0, ALARA Strategies for Tuning During Proton Operations. When a trigger threshold is exceeded, an alarm will appear on the Alarm

Display Task (ADT) monitor in MCR and a response will be required by the on-duty MCR Operations crew to reduce beam losses.)

- ensure authorization from the C-A Department Chair for prolonged high-loss operation with an alarm present
- assign the responsibility for maintaining loss-monitor systems
- verify the operability of beam current transformers and loss monitors used to determine operating efficiencies and losses at start-up of a running period
- perform residual radiation surveys to confirm loss assumptions

A general description of each type of beam-loss monitor in use at C-A Department follows. These devices are common to all C-A Department accelerators and experimental areas.

The "beam-loss monitor" is a device in which the collected charge is directly proportional to the beam loss. The unit consists of an ion chamber, an electrometer with a metering circuit and the necessary power supplies. It can detect radiation over the full range of potential beam loss but the measurement saturates in high-radiation fields. The ion chamber will measure ionizations from any penetrating radiation including x-rays, gamma rays, neutrons and high-energy particles such as pions and muons. There are two types used at C-A Department, one is a length of insulated heliax cable placed along the magnets that circulate or transport the beam. The cable is typically 1-inch in diameter with a 0.4-inch center conductor. The outer shield is biased with 200 volts, and there is a constant-flowing filling gas mixture of argon and ethane between the outer shield and center conductor. The other type is a sealed glass bottle 4-inches long, and 2-inches in diameter. The glass bottle is filled with argon, with two concentric nickel cylinders inside, one with a diameter of 0.25-inches and the other 1.5-inches. The outer cylinder operates at 1400 volts. An electrometer/integrator circuit measures the total charge collected by the center conductor of both types of detectors. Each glass-bottle beam-loss monitor is calibrated using a Cs-137 radiation source and an automated test and evaluation system. The characteristic response curves are fitted and loaded into the software application that displays the data.

The “beam-current monitor,” which is also known as a “beam-current transformer,” is a non-destructive device that is mounted around a ceramic break inserted in a metallic vacuum chamber, in an accelerator or beam line. It measures electric charge contained in a burst of beam, or the electric current generated by a series of beam pulses. The toroidal-shaped device is a ferromagnetic core that is made of high permeability metal tape or made of ferrite. The beam acts as a single primary turn that induces a voltage across a resistor that completes the secondary circuit that is made up of a number of turns of conductor. An additional turn is wound around the core and it is pulsed by a known current source in order to calibrate the system. A specifically designed electronics circuit generates a signal that is proportional to the beam charge passing through the detector.

The “ion chamber” is a semi-destructive detector used primarily in transport beam lines to measure the amount of low intensity charged particle beam passing through a defined time window. It is filled with argon-CO_2 (75%, 25%) at one atmosphere pressure. The voltage bias is set to +450 volts. There are four signal planes sandwiched between five high-voltage planes, and each has 0.635 cm gas-gap on either side. All eight gas-gaps for the four signal planes are summed and this yields a total ion-chamber gas length of 5.08 cm. Electron-ion pairs generated by charged particle beams passing through the gas volume are swept to respective planes by the bias voltage. The current from the signal plane is fed into a current-to-frequency converter module that generates counts that are monitored by the control system. Each count represents a known amount of current collected from the detector. A precision current source is used to calibrate the current-to-frequency converter. The charged particle's efficiency to generate an electron-ion pair is calculated based on widely accepted documented gas properties.

The "segmented wire ion chamber" (SWIC) is similar in design and function to the ion chamber described previously except that its purpose is to measure beam intensity in horizontal and vertical segments by using an array of thin signal wires in each plane instead of a single signal-plane. The voltage bias applied can be increased such that the voltage gradient near the signal wire is sufficient to cause electron multiplication resulting in net signal gain. This is an effective way to measure beam profiles for low-intensity beams. The charges collected on each wire are stored on an integrator circuit. Each channel is read out individually and displayed, and it shows a transverse profile of beam intensity verses position.

The "secondary emission chamber" (SEC) is used primarily in high-energy transport beam lines to measure the amount of high-intensity proton beam passing through. It consists of an evacuated chamber with five aluminum foil planes that are situated perpendicular to the beam trajectory. Three of the planes are high voltage bias, +450 volts, and two of the planes are for signal pickup. The configuration of these five planes is HV-S-HV-S-HV; that is, the signal (S) planes are sandwiched between adjacent high-voltage (HV) planes. As the beam passes through the foils, electrons are released from each of the foil surfaces with an efficiency of about 2.2% per proton. This interaction generates a current that is monitored by processing electronics. These electronics are calibrated based on the efficiency calculation derived from accepted documented beam/foil interactions. The SEC's are also cross-calibrated with beam current transformers when possible.

The "multiwire chamber," also known as a Harp, is used to measure horizontal and transverse beam profiles. As the name Harp implies, arrays of thin wires are suspended in both planes across the evacuated beam pipe aperture. Depending on the energy of the passing beam, either several electrons are knocked off or charge is absorbed resulting in a current flow. Each wire is connected to a processing electronics channel that generates a signal monitored by the controls system. A beam profile is reconstructed and displayed by a high-level application.

The "video-profile monitor," is also used to measure transverse beam profiles. It consists of a thin phosphor screen made of chromium-doped aluminum oxide, zinc cadmium sulfide or gadolinium oxy-sulfide doped with terbium. The thin screen is placed in the beam path. As the charged-particle beam passes through, the phosphor becomes luminescent; that is, at low temperatures a phosphor emits light in proportion to the transverse density of the beam. The light is collected by a nearby video camera, and the video signal is processed by a frame grabber in conjunction with a high-level control application, which calculates transverse beam-shape characteristics. The image is available to be displayed live on a video monitor. The shape of the beam can be tuned by the operation staff to desired parameters, and monitored to ensure transverse characteristics at a specific location.

The "beam telescope" is used to measure fixed targeting efficiency at high-energy proton primary targets. It consists of three scintillator-photomultiplier tube (PMT) assemblies positioned a distance away from the target, at a 90-degree angle from the incident proton beam. These assemblies are able to generate a signal when one minimum ionizing particle passes through the scintillator generating a photon that interacts with the PMT face. The resulting current is amplified by the PMT dynodes that are biased at 1400 volts. The three scintillators are aligned such that only a secondary particle leaving the target at a 90-degree angle will pass through all three detectors, which is similar to three lenses in a telescope, generating a triple coincidence in the signal processing electronics. The beam position and angle are typically scanned across the target until the ratio of beam intensity recorded by the SEC to coincidence counts recorded by the beam telescope is optimized.

“Beam position monitors” (BPMs) represent a class of devices all of which work on the same basic principle that is non-destructive position measurement by coupling to the electromagnetic fields of the passing bunch. There are quite a few different mechanical configurations throughout the C-A Department complex of accelerators and experimental areas. BPMs vary based on number of planes needed at a location, coupling frequency harmonic, aperture size and accelerator ring or transport application.

Beam intensity limiting devices are steel or tungsten “collimators and collimators are considered part of BIS. For example, the collimator used in the RHIC experimental systems is a mechanical device used to remove the beam halo to protect the experiments and accelerator components from excess radiation.

The Chief Mechanical and Chief Electrical Engineers review and approve these instrumentation systems. They use existing procedures in Chapter 9 of the C-A Department OPM. The Chief Engineers identify and mitigate hazards associated with beam instrumentation systems such as electrical shock, flammable gases, effluent releases, pressure and vacuum need.

Hazard mitigation is accomplished by ensuring the instrument design meets National Electric Code and SBMS standards.

The contents of the operating procedures for beam instrumentation systems are such that they instruct MCR operators to perform rudimentary operational checks of a subset of the accelerator instrumentation systems after the appropriate specialist reports that the apparatus is ready for testing. The subset of instruments focuses on those instruments that sense beams that have the potential to damage machine components and/or to create activation. The checkouts of these instruments are adequate to demonstrate normal operation. Checkouts are performed for Linac loss monitors and Fast Beam Inhibit system, Booster Ring loss monitors, AGS Ring loss monitors, circulating-beam monitors and beam position monitors. In the fixed target areas, SWICs are checked for heavy ion running, and SECs are checked for proton running. Additionally, target temperature monitors, phosphorescent screens or flags that are inserted for a few moments into the beam, and movable apertures such as beam collimators that could inadvertently intercept beam, are checked.

3.2.1.1.Beam Instrumentation for Linac

The beam instrumentation for the high intensity proton Linac are the devices used to monitor the beam while adjusting the beam transport through the Linac. They are required while tuning the RF systems to maintain beam quality, keep the beam loss as low as reasonably achievable and indicate the operating conditions. In addition, especially in the high intensity space charge dominated Booster, a transverse or longitudinal mis-match can cause beam halo, which can result in abnormal activation of the accelerator components. Some of the beam line instruments also provide an alert-system to protect the Linac by monitoring anomalously high radiation levels.

The types of the beam line instruments used are beam position monitors, beam current and profile monitors, beam phase monitors and beam loss monitors. The arrangement of these monitors not only achieves efficient beam observation for operations but also allows for beam studies.

The beam instruments at the Linac are arranged as follows:

The section between the ion sources and RFQ is called the low-energy beam transport (LEBT, beam energy is 35 keV). The high current H^- section is provided only with beam current monitoring. The beam energy is low enough that no radiation is produced, and no damage can be done even if full beam loss occurs. Steering and focusing of the beam can be optimized merely by measuring beam current before and after the RFQ, and optimizing RFQ transmission. In the beam line after the much lower intensity polarized H^- ion source, one has the additional capability of measuring beam profiles on a phosphor screen, and the current on one Faraday cup.

The medium-energy beam transport (MEBT, beam energy is 750 keV) is the ~6m connecting section between the RFQ and the Linac. This section needs to be tuned precisely in order to maximize transmission through the Linac. However, the energy is still low enough in the section that one does not produce any measurable radiation, and current loss can only cause minimal equipment damage. Tuning of this line includes setting properly the 12 focusing quadrupoles in the line, and setting the phases and amplitudes of the RF fields in the three buncher-cavities in the line. While the beam emittance, which is the angular spread of the beam at different transverse positions, can be measured with a special device at the entrance to the Linac, the line is primarily set by first setting elements to values calculated by computer model of the optics, and then fine-tuning. Fine-tuning is accomplished by measuring the beam current on the three current transformers in the line, and the current transformers after the early tanks of the Linac.

In the Linac itself, diagnostics include current transformers after each of the nine accelerating cavities, beam position monitors, which also provide beam phase information, after seven of the cavities, and beam profile measurements after six cavities via single horizontal and vertical wires. These wires are stepped through the beam, with the current reading from the wire recorded as a function of wire position. The wire is typically 0.004” diameter tungsten, so the beam current intercepted is extremely low. The current measured comes from secondary electron emission from the wire, thus the name of this device – Secondary Emission Monitor (SEM).

Initial setup of the Linac can be a complicated process, whereby one looks at inter-tank beam-phase information, as well as beam energy information measured by transporting the beam to the HEBT line (see the following paragraph). By measuring curves of the variation of beam phases and energy, as a function of the tanks’ RF phases and amplitudes, and comparing with theoretical computer models of this dependence, one can set the Linac RF to match its design parameters. That is, the phase and voltage of the acceleration fields must produce a beam velocity profile through each cavity that matches the design profile, based on the mechanical properties of each drift tube. Similarly, the Linac drift tube quadrupoles are set to calculated values based on computer models. After this initial setup is done, fine adjustments are made to

RF phases, RF amplitudes, and quadrupole currents based on measured beam loss and beam energy spread measurements made in the HEBT line. One minimizes radiation from beam loss, using the LRM system described in the next paragraph. The initial setup of the Linac is done very infrequently, and a typical yearly turn-on for a run cycle involves only fine-tuning around values archived from the previous year's run.

In the high-energy beam transport (HEBT, beam energy is 200 MeV) section of the Linac, there are beam instruments both for Linac accelerator cavity tuning, and tuning of the beam through the various HEBT transport lines. Profiles can be measured throughout HEBT via about 10 distributed SEM monitors, as well as 4 multiwire profile monitors that give a full beam profile in a single pulse. In addition, there are several beam position monitors, and about 10 beam-current transformers. Once again, beam tuning typically starts with settings archived from previous runs, or computer model predictions. By looking at beam profiles, beam current, and beam loss, quadrupoles and steering dipoles are then adjusted to optimize beam transport and minimize beam loss. One additional diagnostic down the HEBT line allows one to measure beam momentum and momentum spread, which is useful for setting Linac cavity phases and amplitudes. There are both SEM and multiwire profile monitors located at a maximum dispersion point after an 18 degree bend in the HEBT line. Momentum can be determined by noting the dipole field required to center the beam on the profile monitor after the bend, while momentum spread is determined via measurement of the width of the beam profile. For higher resolution measurements, a partially degrading water-cooled slit can be inserted at the object point of this dispersive bend to better define the incoming beam size.

All along the Linac and HEBT, beam-loss monitors are used to identify the local beam loss, which provides an alert-system to protect against damage or component activation due to high beam loss. This is a distributed radiation-monitoring system that allows one to measure and to localize the inadvertent radiation produced by beam loss throughout the Linac. This “long radiation monitor” (LRM) system is a fast radiation measurement done during the beam pulse, and allows one to shut off beam within microseconds if the radiation level is above a preset threshold for any monitor. The detectors are approximately 10 m lengths of 7/8” diameter heliax cable, which are filled with argon to about 10 psig, and biased with approximately 100 V between the center conductor and shield. The detected signal is current resulting from ionization in the cable, ionization from beam-produced radiation. Approximately 30 cable sections provide complete coverage of the Linac and all of the high-energy beam transport sections. Signals from all detectors are brought back to the Linac control room where any one can be viewed on an oscilloscope to aid in beam tuning. In addition, all signals are sampled and held, allowing them to be displayed in the Linac control room as a histogram of all monitors, updated on each Linac beam pulse. All signals are also interfaced to the C-AD control system, so they can be viewed or logged from any control system console throughout the accelerator complex. Finally, and most importantly, all signals from the radiation detectors are fed into comparator circuits having individual reference voltages, thus allowing a tolerable loss pattern to be preset. If any LRM signal exceeds its allowable level, then the comparator output is used to turn off the beam within 5 microseconds, and display the loss location via a flashing light on a map board in the Linac control room.

3.2.1.2.Beam Instrumentation for TVDG

Various beam diagnostic devices are strategically located along the TVDG beam-lines to measure the optical properties and position of the beam. These include Faraday cups, beam-current transformers and beam-profile monitors. All necessary controls such as actuators and amplifiers are provided to make these instruments remotely operable via computer control.

Faraday cups are used for a variety of applications including the accurate monitoring of ion-beam currents. They are all metal and ceramic with a BNC feed-through and electrostatic or magnetic suppression. All beam interaction surfaces are tantalum. Because the Faraday cup absorbs all of the beam's energy, it cannot be used to measure beam current during an experimental run. It instead must be moved into the beam before an experiment, and then out of the way before the experiment can be run.

Unauthorized entry into any access-controlled zone at TVDG during beam operation will result in beam stoppage through the beam inhibit. Beam inhibit is caused by the insertion of redundant Faraday cups. These Faraday cups are utilized as beam stops for many operational conditions and are kept inserted whenever personnel enter the tunnel zones. One Faraday cup actuator is of spring-loaded fail-safe design that will revert to the inserted position in the unlikely event of power or compressed air loss.

The total beam current accelerated by the TVDG is self-limiting. Tandem van de Graaff accelerators, while capable of accelerating virtually any ion species, are very sensitive to the total charge available for the acceleration process. Beam currents from the ion source can be injected into the Tandem at a maximum of several micro-amps DC; accelerated beam currents measured at the higher-energy end of the accelerator are higher in terms of "charge" current due to the increase in charge state from stripping at the terminal. However, the total number of particles after acceleration is always somewhat reduced because the injection, acceleration and stripping processes have efficiencies less than unity. If one were to increase continually the ion source current much above a level of several micro-amps, then eventually, the terminal voltage will "sag' as a result of the inability of the charging system to supply sufficient charge. The consequence of the terminal voltage decrease is a reduction in beam energy, and the resulting lower energy beam cannot be transported around the TVDG analyzer magnet.

3.2.1.3.Beam Instrumentation for Booster and AGS

Instrumentation for the circulating-beam accelerators is combined with associated alarms and is used to provide an indication of an operational situation that could, if ignored, adversely affect the environment. One situation of concern is high-intensity proton operation in the Booster and AGS. Here the instrumentation and alarms guard against excessive beam losses that could result in equipment damage. In the machines that have to cope with high-intensity protons, the C-A OPM has a procedure, "ALARA Strategies for Tuning during Proton Operation," that lays out one system of beam measurements that result in limiting the amount of beam loss permitted during the acceleration and extraction processes. The procedure specifies the instruments that are required, such as current transformers and loss monitors, and the software used to generate alarms if specified levels of losses are measured. The beam-current levels to be respected are also specified by procedure. These levels are the responsibility of the liaison physicist for each step of the acceleration; that is, the Booster Liaison Physicist speaks for acceptable losses for beam coming into and accelerating in the Booster, the AGS Liaison Physicist speaks for the AGS. This instrumentation and procedure become relevant for beam intensities above $5x10^{12}$ protons per AGS cycle. The various levels that alarms constrain operations are based on experience both with beam losses and with equipment failures associated with beam losses. Alarm set points are consistent with reasonably efficient operation at highest intensity running levels.

3.2.1.4.Beam Instrumentation for RHIC and Collider Experimental Areas

The BIS associated with RHIC injection-lines, RHIC itself and RHIC experimental areas helps guard against moving to a situation where potential particle losses could add up to exceeding the limiting dose in an hour defined in the ASE. In RHIC and its injection lines, OPM procedure covers the instrumentation used to guard against excessive beam losses in certain areas. For example, relevant procedures include “RHIC Accelerator Safety Envelope Parameters,” and “Procedure to Monitor Particle Losses in RHIC.” The beam instrumentation systems involved are current transformers and loss monitors, which are in RHIC and its injection lines. The main strategy that keeps RHIC from approaching loss limits is a BIS that limits the number of particles injected into RHIC each hour. The details are spelled out for operators in a procedure that specifies the relevant software required to generate the required alarms. This type of “particle-monitoring” procedure is generated before each running period but may be re-generated quickly during periods when operations systems are revised. For example, if software is changed or instruments are replaced during shifts. This type of particle-monitoring procedure follows similar review and approval steps as the permanent procedures in the C-AD OPM; however, training requirements allow shift personnel to train on revised procedures without interrupting the accelerator schedule. In the RHIC BIS, the alarm levels set are simply derived from the radiation levels to be respected. The levels are verified from fault studies carried out to associate beam intensity lost with measured dose. The details of fault studies are documented by the C-A RSC.

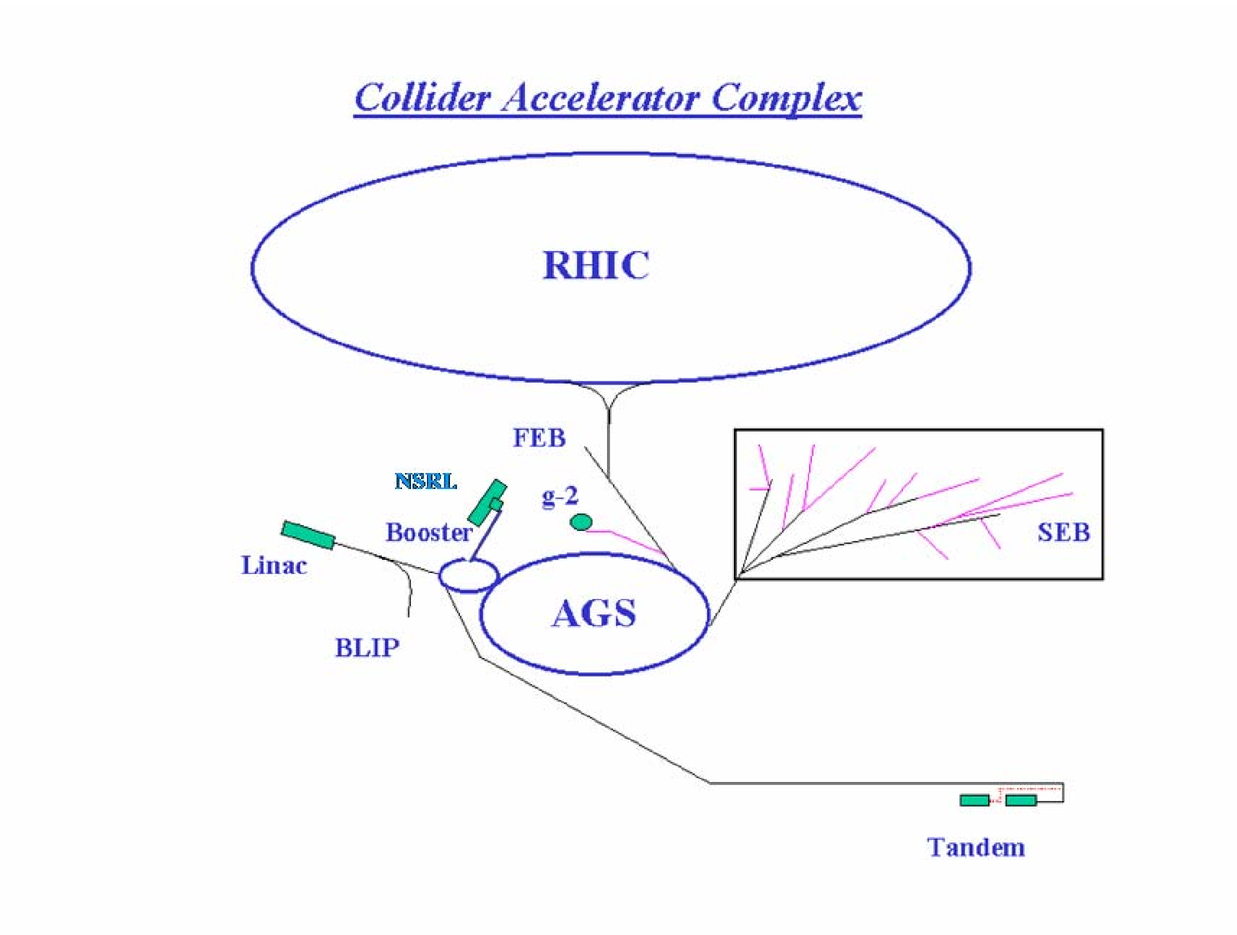
3.2.1.5.Beam Instrumentation for Experimental Beams Lines for Fixed Targets

The beam instrumentation systems (BIS) associated with the experimental beam lines associated with the fixed targets guard against moving to a situation where radiation damages equipment or causes unwarranted activation. Although radiation levels must also be respected in the experimental areas, the instrumentation systems used for personnel radiation protection are part of a higher quality, fail-safe system known as the Access Control System (ACS).

Booster receives and accelerates protons from Linac and heavy-ions from Tandem. Following acceleration, protons or heavy-ions may be slow extracted from Booster into the NSRL experimental area, or fast extracted into AGS, where particles are further accelerated to higher energies. Protons or heavy-ions may be “slow external beams” (SEB) from AGS into the switchyard or “fast external beams” (FEB) from AGS into a line that leads to the U and V fixed-target areas. FEB may also go to RHIC, where two opposing beams are injected, accelerated and collided. If slow-extracted high-intensity protons enter the switchyard located at the onset of the

SEB, then the proton beam is split twice into four primary beam lines that impinge onto special targets in order to produce secondary beam lines. In the case of heavy ions or polarized protons entering the switchyard in SEB, the beams proceed directly into experimental areas without producing secondary beams. See Figure 3.2.1.5.

Figure 3.2.1.5 Booster and AGS Extracted Beam Lines and the Collider



At the design stage for a beam line, beam-line optics and the placement of the respective magnets are determined using special beam-transport software that simulates the intended beam parameters. These software codes trace the beam passage through the electrostatic and magnetic elements from the source to the targets. Of primary concern is the delivery of beams with the proper characteristics assuring containment inside the beam pipe with minimal losses. Beam dumps are designed to assure that the beam is dissipated in a controlled fashion without adverse impact on the environment, such as unintended soil activation. At the design stage, beam-transport software helps determine the types of instrumentation that will be used for beam control; that is, the devices that make up a specific BIS.

In order to assess beam conditions and status in real time, the BIS for extracted beams and secondary beams is composed of several types of instruments. Beam instrumentation systems for measuring beam intensity consist of SECs, current transformers, ionization chambers and beam telescopes that view the targets. Beam instrumentation systems used to monitor beam position consist of florescent flags, beam-position monitors and SWICs. Beam losses inside the target caves are assessed using beam-position monitors. Particle fluence rate[7] outside the caves may be assessed indirectly in units of particles per cm^2 per second using "Chipmunk" radiation monitors; however, because of their role as a personnel safety interface, Chipmunks measure radiation levels directly in units of mrem/h and are part of the ACS and not the BIS.

The type of instrumentation used in the BIS for extracted beams is commensurate with application such as type of extraction, desired beam intensity and spot size. All BIS instrumentation is calibrated on a periodic basis, typically before each running period. The calibration and testing is performed by the Beam Components and Instrumentation Group who use procedures and checklists.

[7] Note: The name "flux density" has units of particles per cm^2 per second, and is a name that is sometimes used instead of "particle fluence rate."

Tuning and fault studies involve the use of the calibrated and tested BIS. Consistent with C-A Department ALARA policy, after a beam line is designed and components installed, the liaison physicist tunes the beam to confront design with reality and assure clean delivery of beam to the desired target. Fault studies are carried out and documented to ensure that beam enclosures are properly specified and constructed to contain any accidental radiation losses. It is noted that instrumentation from the Radiological Controls Division or instrumentation in the ACS are used for radiation measurements related to personnel protection, while BIS is used to tune the beam or to detect the location of beam loss.

While the beam line design and intended operation is subject to review by the RSC, the BIS is only subject to review by the liaison physicist since the BIS serves only to protect equipment and to tune the desired beam in order to meet an experimenter's needs. On the other hand, the RSC reviews ACS instrumentation that is specifically designed to assure that proper beam operations minimally influence personnel or the environment. For example, Nuclear Measurements Corporation (NMC) instruments, which have scintillation paddle detectors, are positioned directly in the beam with their output calibrated versus beam intensity. Chipmunks, which are tissue equivalent gas-filled ion chambers, are positioned at potentially occupied locations outside the shielding, and their output logged. Both NMCs and Chipmunks are interlocked to shut down the beam at preset RSC-approved radiation levels in case beam strays due to magnet failure. In addition, current comparators are used by the RSC to make certain that a particular beam stays in its particular channel or that it does not exceed a certain set momentum.

The liaison physicist, who is responsible for tuning the beam using the BIS, is also responsible to generate check-off lists that ensure ACS instruments are in place before tuning begins. The RSC Chair and C-A Department Chair or designees approve these check-off lists for each beam line, and MCR operators must possess a completed checklist before resetting the line for beam operations.

In order to detect long-term low-level losses, daily radiation surveys are carried out around the perimeters of operating beam lines. Low-level beam losses may be tolerated by the BIS or ACS but may not be ALARA. Routine radiation surveys are performed by RCTs using portable calibrated instruments designed to detect neutrons and photons. The surveys are logged and kept for future reference. Beam operations data, which includes these radiation surveys, are monitored by the liaison physicist responsible for a specific beam line on a periodic basis to evaluate beam status, to assure that the desired beam tune is being adhered to and to ensure that the beam line is operating with minimal losses. Procedures that help ensure this practice is carried out by liaison physicists, procedures such as such as “Transport Beam Tune Maintenance,” are kept up-to-date in the C-A Department OPM.

3.2.2.Design Criteria and As-Built Characteristics for Access/Beam Control Systems

3.2.2.1.General Design Criteria for Access Control System (ACS)

This section describes the general design criteria for the access/beam control system (ACS). The Department’s ‘classification’ scheme for all radiological areas at C-A Department defines the nature and extent of the access/beam control systems. The ACS prohibits access or limits the radiation dose when the radiological areas are accessed. Table 3.2.2.1 delineates the access, enclosure and minimum system requirements, for each C-A Department ‘classification,’ and takes into account the potential levels of radiation during normal operations, and the potential increases in radiation levels with abnormal conditions.

The three allowed access modes are procedural access, Restricted Access and Controlled Access. The control of each allowed access mode, except procedural access, is under the purview of Main Control Room (MCR) operators who select the appropriate mode. Procedural access requires management approval.

In the Restricted Access mode, the doors to the enclosure are locked. Personnel require a key or a magnetic card for entry. TLDs are required for radiation fields greater than 5 mrem/h, and in radiation fields greater than 100 mrem/h, digital alarming dosimeters are required. For unescorted entry, personnel are required to have appropriate radiological training and Collider-Accelerator Department area-specific access training. Personnel meeting these requirements may enter the area unescorted if they also meet the conditions of the applicable Radiation Work Permit (RWP) when access is allowed to the enclosure.

In the Controlled Access mode, MCR Operators ‘sweep’ the area clear of all personnel, then allow trained and authorized persons to enter and exit the area while keeping a log-in/log-out record and a gate watch. The operator may be stationed at the gate or be remotely located and able to view an entrant via video camera. The operator controls the opening of the gate. In some cases, bio-identification access systems are used to log entry and exit into an area under Controlled Access and to permit the individual to take a key from a key tree. In Controlled

Access mode, an Operator is permitted to reset an area for beam without a re-sweep provided the gate watcher or bio-identification unit ensures all personnel have logged-out of the area.

MCR Operators can place an enclosure in access-prohibited mode and subsequently enable the beam after the enclosure is swept and the area resets are complete. Both the local resets and remote resets must be complete. An area-reset state ensures that the sweep status of the enclosure has not changed. Primary beam enclosures are enclosures containing uncollided beam capable of producing whole-body dose rates in excess of 50 rem/h. Secondary beam enclosures are enclosures that contain the beams resulting from primary beam interactions at fixed targets. The hazard from secondary beams may vary from being as high as from the primary beam itself, to levels not requiring access controls. Upon MCR reset of a beam enclosure, a visual warning in the enclosure is displayed, an audible warning sounds and a timer starts before beam can enter the enclosure. The timer varies for each accelerator, and it ranges from 30 to 90 seconds. If a person remains inside a reset area, he/she can use emergency-stops (crash-buttons or crash-cords), which are located throughout the beam enclosures. They are visible under emergency lighting conditions. An emergency stop requires local resetting. The status of emergency-stops is monitored in the MCR.

The term beam-enabled indicates functional status and the presence of beam or the potential presence of beam. Under this condition, there is the potential to create undesired radiation in nearby occupied areas. Access to areas that are contiguous to beam-enabled areas are also evaluated and classified by the RSC, and appropriate access controls are established.

In the access-prohibited mode, areas may be fenced with locked gates, or if levels could exceed 50 rem/hr (C-A Department Classes I and II), the access/beam control system disables slide bolts or electric strikes on all access doors. In Class I and II areas, all access paths have a minimum of two sensors to detect an open door and disable the radiation source.

For Class I and II areas, an interlock trip causes two independent critical devices to disable the radiation source. Additionally, each access gate is equipped with a bolt-home micro-switch to indicate that the gate is locked. The status of these gates is monitored from the MCR. For Class III and IV areas, the gates must be locked and have a sensor that monitors if the gate is closed or opened. If opened, the ACS disables the beam. For Class V and VI areas, gates are locked, but not monitored, when access is prohibited.

The access control system inhibits beam via hardwired critical devices or critical circuits. The terms dual or redundant means two independent critical devices or interlock systems are used or required. Each device or interlock system is isolated from the other to perform a similar safety function, such that any single failure will not result in the loss of protection. Fail-safe means that predictable failures of the system leave the ACS in a safe mode. The de-energized state of relays used in the ACS is the fail-safe state.

Active types of access control systems are either electronic devices such as radiation monitors, or written procedures. Procedural access is an access where requirements are enumerated in the RWP and other work documents in order to make the area safe for occupancy. Active devices, on the other hand, make the area safe when they sense unwarranted levels of radiation or beam current, or when they sense excursions outside the preset limits for electrical signals. Hardwired normally refers to mechanical switches, mechanical devices and electromechanical relays. The RSC has the authority to classify active devices as hardwired devices if the design is sufficiently robust and appropriate engineering reviews are done.

Currently, three active devices are classified as “hardwired” by the RSC: (1) interlocking chipmunk area-radiation monitors, (2) interlocking Nuclear Measurements Corporation (NMC) units and (3) Rochester Instruments, Inc. "Fail-Safe Trip" units.

A bypass is a temporary task-specific defeat of a single interlock function or group of functions. Modification of the ACS means reconfiguring the interlock system for routine operations. Modification and bypass may follow different administrative approval processes at C-A Department. While documentation of bypasses and modifications must be in accord with procedures located in OPM Chapter 4, bypasses may also be performed under the purview of the RSC using fault study procedures in OPM Chapter 9.

There are five basic design criteria for the ACS that applies to all C-A Department beam enclosures:

- either the radiation is disabled or the related access control area is secured
- only wires, switches, relays, programmable logic controllers (PLCs) and RSC approved active fail-safe devices are used in the critical circuits of the system
- the system is designed to be fail-safe; for example, where relays are used, the de-energized state of a relay is the fail-safe state
- redundant critical devices are used to disable the beam and redundant interlocks are used to secure the area if the dose rate can exceed 50 rem/h
- if a beam fails to be disabled as required by the state of its related access control area, then the upstream beam is disabled; that is, the access controls have backup or what is sometimes termed “reach-back”

The RSC reviews and approves changes to the ACS. They approve the critical devices and they establish the conditions that the ACS must monitor. For example, they approve electric current in beam elements, the position of moveable beam-components or the position of access gates. The RSC establishes the alarm level and interlock level for Chipmunk area radiation monitors that may be interfaced with the ACS.

During commissioning periods for new or modified accelerator facilities, radiation surveys and fault studies are conducted by the RSC to verify the adequacy of the shielding and the radiological area classification. The resulting area classifications, which are confirmed by direct radiation measurements as opposed to calculations, confirm the appropriateness of the as-built ACS. The relationship between area classification and ACS requirements is indicated in Table 3.2.2.1. Note the term ‘active’ means an interlocking radiation monitor or other electronic device of some approved type (see C-AD OPM 9.1.11 for additional information). The table shows the following:

- Column 1 – the C-A classification of an area and corresponding 10CFR835 name for the area
- Column 2 - the corresponding radiation dose rate or range of dose rates
- Column 3 - the equivalent radiation levels as in column 2 but in terms of beam-fluence rate
- Column 4 - the training and access requirements to enter the area when beam is enabled
- Column 5 - the sweep and reset authority for the area required to enable beam
- Column 6 - the area enclosure or barrier requirements
- Column 7 - the C-A classification for normal operations and the *C-A classification if the beam fluence rate could be accidentally increased to a higher C-A Class*

- Column 8 – the minimum Access Control System hardware for normal operations and t*he minimum Access Control System hardware if the beam fluence rate could be accidentally increased to a higher C-A Class*
- Column 9 – The purpose of the Access control System for normal operations and the purpose of the Access Control System *if the beam fluence rate could be accidentally increased to a higher C-A Class*

The procedure for review of new or modified ACS designs requires the liaison physicist assigned to a beam line or accelerator to describe the radiation issues and protection methods to the RSC in a written description. The RSC reviews and makes recommendations on the interlock system with special attention to defining the classification of the area and the corresponding ACS. The RSC assigns a subcommittee to review the final interlock design upon its completion. Meeting minutes or a memorandum noting the details of the design as approved by the sub-committee are distributed to all RSC members. A full RSC review of the logic is done if an RSC member finds the recommended solution to be deficient. The approved logic diagram or state table, and the approved wiring diagram become controlled documents.

Table 3.2.2.1 General Guideline for C-A Radiation Access-Control System Classification and Application

ACS –Access Control System; HFD-Hardwire, fail-safe, dual; HF-Hardwire, fail-safe; AFD-Active, fail-safe, dual; AF-Active, fail-safe; H-Hardwired; AD-Active, Dual; A-Active

C-A Class Area Name with Access as per 10CFR835	Radiation Level (Allowed potential whole body dose with access)	Equivalent 30 GeV Large Beam Proton Fluence Rate,[a,b,c] (cm^{-2} h^{-1})	Access When Beam Enabled	Sweep/Reset Authority	Area Enclosure	C-A Class (Radiation Level) *C-A Class without Access*	Minimum ACS *Additional ACS at this Class Level*	Purpose of ACS for Operational Class *Purpose of ACS for Class*
Class I Very High Radiation Area -	>500 rad/hr [a]	>3.9x10^9	Absolute Prohibition	MCR Operator or Radiation Safety Committee (RSC) Designate	Impregnable Enclosure, Dual Interlocked Gates	I *Not Applicable*	HFD *Not Applicable*	Preventing Access or Beam Enabled *Not Applicable*
Class II High Radiation Area-	<500 rad/hr >50 rem/hr	<3.9x10^9 >1.1x10^8	Special Radiological Control Division (RCD) Approved Procedure	RSC Designate	Fully Enclosed, Dual Interlocked Gates	II *I*	HFD *Not Specified*	Controlling Access or Beam Enabled *Preventing exposure to these levels*
Class III High Radiation Area -	<50 rem/hr >5 rem/hr	<1.1x10^8 >1.1x10^7	RCD Technician Supervision	RSC Designate	Walls or Fences, Interlocked Gates	III *II* *I*	HF *AF* *HF*	Controlling Access or Beam Enabled *Preventing exposure to these levels* *Preventing exposure to these levels*
Class IV High Radiation Area	<5 rem/hr >0.1 rem/hr	<1.1x10^7 >2.3x10^5	Individual Authorized by the RSC	Individual User May Be Authorized by the RSC	Walls or Fences, Locked Gates	IV *III* *II* *I*	H *AF* *HF* *HFD*	Control Access or Beam Enable *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*
Class V Radiation Area	<0.1 rem/hr >0.005 rem/hr	<2.3x10^5 >1.1x10^4	Radiation Worker or Visitor Escorted by Radiation Worker	When Required, Individual User Authorized by the RSC	Fences or, Ropes; Radiation Warning Signs Every 40 ft	V *IV* *III* *II, I*	A *A* *HF* *HFD*	Alarm on Excessive Radiation *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*
Class VI Controlled Area	<0.005 rem/hr >0.00005 rem/hr	<1.1x10^4 >1.1x10^2	General Employee Radiation Trained Individual or Escorted Visitor	Not Required	Signs, Fences or, Ropes at Perimeter; Posted at Entrances	VI *V* *IV* *III* *II, I*	A *A* *H* *HF* *HFD*	None *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*

a See C-A OPM procedures for small beam sizes.
b If the absorbed dose rate is 500 rad/hr or greater, the area is named a "Very High Radiation Area" as per 10CFR835.
c This is the fluence rate from a beam of 30-GeV hadrons with size greater than 1000 cm^2. It corresponds to the dose rate listed in column two.

3.2.2.2. Example As-Built Characteristics for the Access/Beam Control Systems

3.2.2.2.1.NASA Space Radiation Laboratory (NSRL)

The Access Control System (ACS) for the NSRL is an example of the type of ACS installed at C-AD facilities. The NSRL ACS contains gates, labyrinth entrances, video cameras, bio-scanners, etc. that are typical of modern systems. The NSRL ACS controls four gates that lead to the beam line or Target Room:

- labyrinth entrance from the Support Laboratories (BGE1)
- labyrinth entrance from the beam-line shield door (BGE2)
- internal isolation gate at the upstream end near the Target Room (BGI1)
- internal gate at the upstream end of the beam line (BGI2)

BGE1 and BGE2 are normal external access gates and are instrumented to disable NASA Space Radiation Laboratory extracted beam. BGE2 is designed to allow beam line access for large items; for example, a vacuum leak checking station. BGI1 allows unrestricted egress from the NSRL tunnel into the Target Room but requires, in some access control configurations, a Controlled Access (CA) key and simultaneous release from the Main Control Room for movement from the Target Room to the NSRL tunnel. BGI2 isolates the long straight section of the NSRL tunnel from the beam line segment contiguous with the Booster penetration. A small shield-labyrinth is used in this region to mitigate the impact of beam loss in the Booster ring. BGI2 is instrumented to disable the Booster injected beam for both the Linac and the Tandem.

Figure 3.2.2.2.10.a shows the layout of Access Control System for NSRL. The Figure shows gates (BG#), video cameras, bio-scanning device, key tree, beam-imminent warning devices (CB#), sweep zones (NASA Space Radiation Laboratory-Z#) and crash operators (CO#). A picture of the system at the entrance to the interlocked areas is shown in Figure 3.2.2.10.b. Each person entering the target room during a run has primary responsibility for his or her own safety. Access to the target area is gained using a card reader or the iris-scanner/token-key depending on the operational state of the beam line. Only properly trained individuals can access this area. There are two operational states or modes of access defined as, “Restricted” or “Controlled.” When the target room is in a “Restricted Access” state, which is evinced by a green state-light (see ‘1’ in Figure 3.2.2.2.10.b), the doors to the target room will open with a placement of an access card on the card reader. This is the normal state of the system when beam is not being used for Radiobiology experiments. When the target room is in a “Controlled Access” state, which is evinced by an orange state-light (1), access is granted only to those with appropriate training, a key from the key tree and with a simultaneous release of the gate locks by both the user and a Main Control Room (MCR) Operator. This mode is the usual mode of access during radiobiology runs. The beam is interrupted for several minutes while the access is made then returned once the access is complete. The verification-of-training is achieved by the iris-scanner (see ‘2’ in Figure 3.2.2.2.10.b), which, upon recognition, will display the user’s name in the control room. This allows the MCR Operator to write down the user’s name in the log sheet, and it will release one of the token-keys (see ‘3’ in Figure 3.2.2.2.10.b) to the user. The key is then inserted into the key release, which is shown as ‘4’ in Figure 3.2.2.10.b. The user carries

the token key into the area. The beam cannot be operated until the key is re-captured in the token-key box and the interlock is reset by MCR.

Figure 3.2.2.2.10.a NSRL Access Control System Layout

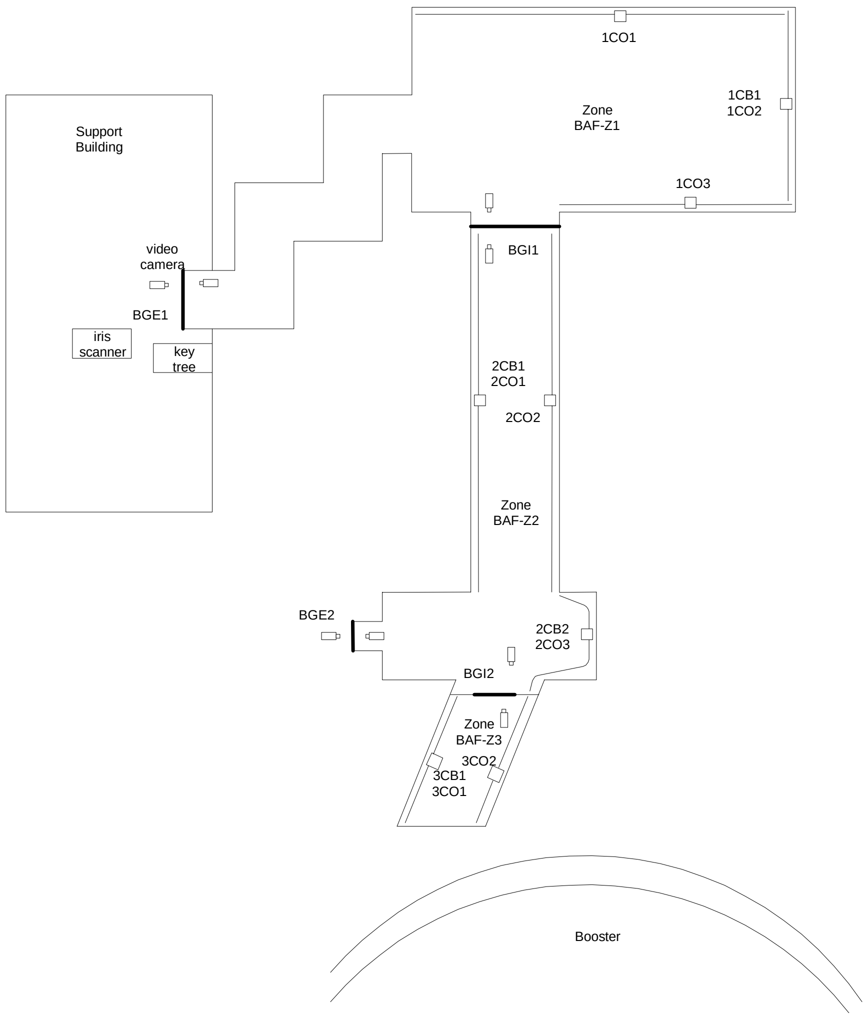
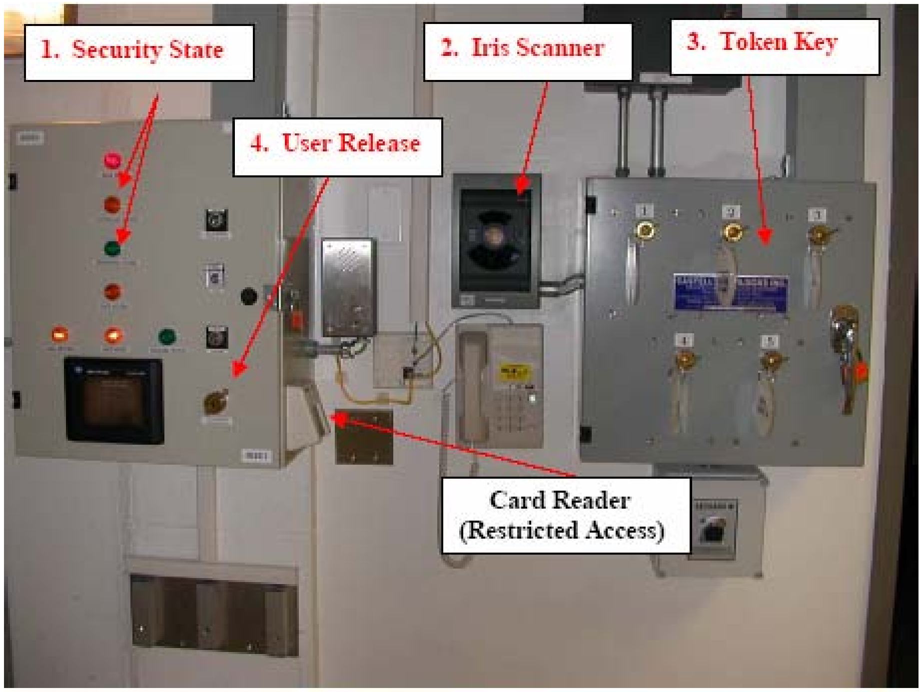


Figure 3.2.2.2.10.b Picture of NSRL Access Control System



3.2.3. Design Criteria and As-Built Characteristics for Fire Protection Systems

3.2.3.1. Design Criteria

The following presents the philosophy for the physical fire protection for the C-A Department. This philosophy establishes the methodology that was used in each Fire Hazard Analysis (FHA) for determining design requirements and choosing the most effective fire protection features.

The physical fire protection design meets the objectives of DOE Order 420.1, "Facility Safety." Implementation of the requirements follows the guidance provided in the

"Implementation Guide for use with DOE Orders 420.1 and 440.1, Fire Safety Program" (DOE Document G-420.1/B-0, G-440.1/E-0, dated September 30, 1995).

The primary means to document physical fire protection DOE 420.1 requirements are with Fire Hazards Analyses (FHA). The FHA identifies fire hazards and required physical fire protection that is incorporated into an evolving accelerator and experimental program in accordance with applicable DOE Orders, codes and standards. Key compliance documents include:

- the Standard Building Code (SBC), 1997 Edition
- National Fire Protection Association Codes and Standards
- BNL ESH Standard 4.0.0 Fire Safety Program, Rev. 0

If the listed codes and standards are silent on, or do not apply to a specific fire hazard, additional documents, such as Factory Mutual Data Sheets, are used based on direction from the BNL Fire Protection Engineer or designee. Any additional documents, and the reason for their use, are identified in the FHA.

The DOE Authority Having Jurisdiction (AHJ) must approve NFPA, SBC or SFPC deviations. The BNL Fire Protection Engineer or designee is responsible for acting as the interface between BNL and the DOE AHJ to obtain written approval of deviations from the DOE AHJ (DOE Order 420.1 Section 4.2.1.11 and DOE 440.1A, Attachment 1, Section 2.b.).

Each FHA was performed using the guidance provided in the "Implementation Guide for use with DOE Orders 420.1 and 440.1, Fire Safety Program" and all design related topical areas listed in this guideline were addressed. An FHA was performed for each significant facility to identify fire hazards and the acceptable level of physical protection (fire protection systems and building components) that are incorporated into the design. Recommendations are not made in the FHA itself, but are provided in a Design Review Record. The FHAs incorporate programmatic considerations. The FHAs were performed under the direction of a qualified fire protection engineer.

Required physical fire protection design features are identified in each FHA. In many cases, various means are available to meet the general criteria required by the DOE Order 420.1. The following guidelines were used in selecting the appropriate protection methods:

- wherever possible, passive protection methods are given preference over active systems
- fire rated or non-combustible construction, barriers and spatial separation are first reviewed for the ability to achieve the required level of protection before suppression systems are considered
- non-combustible materials are used wherever feasible to minimize the hazard
- active suppression systems are provided where required by the referenced documents
- wherever possible, wet pipe sprinklers are used, dry pipe for potentially freezing areas, and deluge for high challenge systems
- alarm and detection systems are provided where required by the referenced documents; type of detection is based on the type of fire expected, and the need for sensitivity or fast response, to provide for rapid manual response or effective process shutdown to minimize damage
- where building Maximum Possible Fire Loss (MPFL) values exceed $50M, buildings are subdivided into fire areas with an MPFL value less than $50M; where this approach is not operationally feasible, redundant fire protection systems are provided

- for facilities where DOE orders or referenced code requirements cannot be met, the need to develop an exemption or equivalency is identified

3.2.3.2.List of Fire Protection Codes, Standards and Design Guides

The following is a list of codes, standards and design guides that apply to Fire Protection. Any additional documents, and the reason for their use, are identified in the appropriate FHA. These codes, standards and design guides apply to facilities built in the last 10 years. Older facilities may comply with all or part of these standards.

- Americans with Disabilities Act of 1990, Public Law 101-336
- New York State Building Code, Latest Issue
- Occupational Safety & Health Act, 29 U.S.C.A. 651
- 29 C.F.R. 1910 - Occupational Safety & Health Standards
- DOE Order 440.1 - Worker Protection, Attachment 1, Section 5 (h)
- National Electric Safety Code
- ADA Accessibility Guidelines for Buildings and Facilities, January 1998
- Standard Fire Prevention Code (1997)
- NFPA 1 Fire Prevention Code (1997)
- NFPA 13 Installation of Sprinkler Systems (1996)
- NFPA 14 Installation of Standpipe and Hose Systems (1996)
- NFPA 17A Wet Chemical Extinguishing Systems (1998)
- NFPA 22 Water Tanks for Private Fire Protection (1998)

- NFPA 24 Private Fire Service Mains and their Appurtenances (1995)
- NFPA 30 Flammable and Combustible Liquids (1996)
- NFPA 45 Laboratories Using Chemicals (1996)
- NFPA 50A Gaseous Hydrogen Systems (1994)
- NFPA 50B Liquefied Hydrogen Systems (1994)
- NFPA 55 Compressed and Liquefied Gases in Portable Cylinders (1998)
- NFPA 70 National Electric Code (2002)
- NFPA 72 National Fire Alarm Code (1996)
- NFPA 75 Electronic Computer/Data Processing Equipment (1995)
- NFPA 80A Protection of Buildings from Exterior Fire Exposure (1996)
- NFPA 90A Standard for the Installation of Air Conditioning and Ventilating Systems (1996)
- NFPA 92A Smoke Control Systems (1996)
- NFPA 101 Life Safety Code (1997)
- NFPA 110 Emergency and Standby Power Systems (2002)
- NFPA 111 Stored Electrical Energy Emergency and Standby Power Systems (1996)
- NFPA 214 Water Cooling Towers (1996)
- NFPA 231C Rack Storage (1998)
- NFPA 299 Wildfires (1997)
- NFPA 318 Protection of Clean Rooms (1998)
- NFPA 750 Water Mist Protection Systems (1996)
- NFPA 780 Lighting Protection Systems (1997)
- NFPA 801 Facilities Handling Radioactive Materials (1998)

- NFPA 1141 Planned Building Groups (1998) [hydrant location only]
- DOE 420.1 Facility Safety
- DOE O 420.2 Safety Accelerator Facilities

3.2.3.3. As-Built Characteristics for Fire Protection Systems

The following fire-protection characteristics apply to all areas. As-built characteristics and/or design exceptions for specific areas are listed in Fire Hazard Assessments (FHAs) in appendices.

Brookhaven National Laboratory provides central fire-alarm station coverage by an Underwriter Laboratory listed multiplexed Site Fire Alarm System. The system complies with the requirements of NFPA 72 for a Style 7D System.

The system uses the existing site-telephone cable plant. RS232 signals are sent via full duplex line drivers. Each fire alarm panel has two channels connected to the Central Station. The panels are divided into 7 communication “loops.” The system can monitor more than 20,000 points. It is currently monitoring 3,800. Response time from alarm at the panel to alarm indication at the Central Station is less than 10 seconds, which is well within the 90 seconds allowed by NFPA 72.

The main console is at the Firehouse, Building 599. This station monitors all fire alarm signals, trouble and communication status alarms. A satellite station at Safeguards and Security, Building 50, receives only the fire alarm signals. If the Firehouse does not acknowledge an alarm within 90 seconds, the satellite station at Building 50 will receive an audible indication to handle the alarm. A second satellite station at AGS Main Control Room, Building 911, receives only the fire alarm signals from the RHIC/AGS accelerator buildings. A team of operators and Radiological Control Technicians respond during accelerator operating times. The ESH Coordinator, Collider Accelerator Support and Radiological Control Technicians respond during accelerator shutdown periods.

The following also apply to all fire detection/protection systems:

- when provided, fire detection is spaced at a maximum of 400 sq. ft. per detector
- alarm devices are supervised for circuit trouble and ground fault conditions by the facility's main fire alarm panel
- alarm and trouble signals report to the BNL Fire/Rescue Group via the Site Fire Alarm System
- water supply control valves to sprinkler systems are supervised by the Site Fire Alarm System
- manual fire alarm stations are provided at each exterior exit
- building occupants are alerted throughout the facility by combination fire alarm bells with integral strobe lights
- only Underwriter's Laboratory (UL) approved or listed equipment is used and it is used in the manner intended by the approval agency to ensure the most reliability

The following facilities have been reviewed for life safety and fire hazards. We note that DOE Order O440.1a, paragraph 4.2.1 indicates DOE contractors shall develop FHAs for all nuclear facilities, significant new facilities, and facilities that represent unique or significant fire safety risks. The list of C-AD facilities that meet that criterion is given in Table 3.2.3.3. The FHAs are posted at the C-AD web-site.

Table 3.2.3.3 List of Fire Hazards Analyses

Facility Description and Fire Hazard Analysis Link	Address	Year Built	Order of Preparation
Booster Applications Facility (NSRL)	Thomson Rd.	2002	1
Tandem Van De Graaff	59 Cornell Ave.	1968	2
Tandem to Booster Tunnel (TtB)	Grids 54,64,74,75	1985	3
200 MeV Linac	16 Fifth Avenue	1969	4
Booster Tunnel	Grid 54-64	1987	5
Siemens MG Power Supply	10 Cockcroft St.	1969	6
AGS RF Power Supply	12 Cockcroft St.	1969	7
C-AD Main Control Room and Westinghouse	35 Lawrence Dr.	1956	8
AGS Tunnel	35 Lawrence Dr.	1957	9
AGS Experimental Hall (Building 912) and BRAHMS and PHOBOS (Experiments at RHIC)	35 Lawrence Dr. and Ring Rd.	1958 and 1981/1994	10
Fast Extracted Beam Tunnels (U, V, W)	2 Thomson Rd.	1962	11
AGS to RHIC Transfer Line	Thomson Rd.	1971	12
RHIC Injection (W, X, and Y Lines) and Ring	Ring Rd.	1981	13
RHIC Cryogenic Control Room /Compressor Building	Ring Rd.	1981	14
RHIC RF Power Supply	Ring Rd.	1981	15
STAR Experiment	Ring Rd.	1981	16
PHENIX Experiment	Ring Rd.	1981	17
EBIS at Linac	16 Fifth Avenue	2006	18
RSVP Experiments (Building 912)	35 Lawrence Dr.	2006	19
eCooler	Ring Rd.	2007	20

3.2.4. Design Criteria and As-Built Characteristics for ODH Protection Systems

The Occupational Safety and Health Administration (OSHA) Respiratory Protection Standard (29CFR1910.134) defines an oxygen-deficient atmosphere as an atmosphere with an oxygen content below 19.5% by volume.

Collider-Accelerator staff is not exposed to an oxygen-deficient atmosphere under normal working conditions. If work needs to be performed in an oxygen-deficient atmosphere, specific work planning is conducted to ensure compliance with OSHA requirements. Persons exposed to reduced-oxygen atmospheres may experience adverse health consequences, including unconsciousness, or death.

On the other hand, events may occur such that an oxygen deficient environment is inadvertently created. Such events may occur in facilities that normally use significant amounts of gas such as helium, nitrogen or sulfur hexafloride. These include the Tandem van De Graaff accelerator rooms, an experimental area such as the g-2 muon storage ring, and many of the facilities at the RHIC. The methodology for assessing and classifying workplaces whereby abnormal conditions have the potential for producing an oxygen-deficient environment is given in BNL's SBMS.

Air normally contains about 21% oxygen with the remainder consisting mostly of nitrogen. Individuals exposed to reduced-oxygen atmospheres may suffer a variety of harmful effects. If exposure to reduced oxygen is terminated early enough, effects are generally reversible. If not, permanent central nervous system damage or lethality results. Major effects hindering escape from the vicinity of an oxygen deficiency are disorientation and unconsciousness. In addition, at facilities that use cryogenics, noise and cold are created in a leak event, and these hinder escape. If it is possible for C-A Department staff to be exposed to an atmosphere containing less than 19.5% oxygen following an accidental release of gas, then hazards are identified and control measures implemented to minimize the risk.

Depending on ODH Hazard Class, up to nine types of controls measures are used at C-A Department, see Table 3.2.4.a. ODH control measures may include warning signs, ventilation, medical approval as ODH-qualified, ODH training, personal oxygen monitor, self-rescue supplied atmosphere respirator, multiple personnel in communication, unexposed observer, and self-contained breathing apparatus. Warning signs and ventilation, controls listed as one and two in Table 3.2.4.a, are considered environmental controls. ODH signs are posted to warn potentially exposed individuals, and the minimum ventilation rate during occupancy is designed to be at least one volume change per hour, which may be accomplished by any reliable means. Higher-level controls, controls listed as three through nine, apply to individuals who have been classified as ODH-qualified. If individuals enter ODH Class 1 through ODH Class 4 areas unescorted, then they must have medical approval from the Occupational Medical Clinic (OMC).

For ODH Class 0 and greater, individuals receive training in oxygen deficiency hazards and safety measures associated with the operation. Retraining is required and training is the responsibility of the C-A Department. For ODH Class 1 and greater, the C-A Department also issues Personal Oxygen Monitors (POM). Each monitor has a unique identifying number and a sticker indicating the date due for calibration. The calibration frequency is every six months. The calibration sticker on the monitor is checked before use. Individuals also have ready access to Self-Rescue Supplied Atmosphere Respirators (SRSARs) during the work. Prior to working in an ODH Class 1 or greater area, personnel test the operation of their POM and verify the readiness of their SRSARs.

For ODH Class 2, more than one individual shall be present. For ODH Class 3 and greater, all personnel engaged in the operation are required to be in continuous communication with an observer who cannot be exposed to an oxygen deficiency. The purpose of the observer is to summon the Fire/Rescue Group in case of need. For ODH Class 4, individuals must wear a self-contained breathing apparatus (SCBA) during the operation. Prior designation as medically fit to wear an SCBA by the OMC is required before training in SCBA.

Table 3.2.4.a ODH Control Measures

	ODH Hazard Class				
	0	1	2	3	4
Environmental Controls					
1. Warning signs	X	X	X	X	X
2. Ventilation			X	X	X
ODH-Qualified Personnel Controls					
3. Medical approval as ODH-qualified		X	X	X	X
4. ODH training	X	X	X	X	X
5. Personal oxygen monitor		X	X	X	X
6. Self-rescue supplied atmosphere respirator		X	X	X	
7. Multiple personnel in communication			X		
8. Unexposed observer				X	X
9. Self-contained breathing apparatus					X

X = Required

Specific areas at Collider-Accelerator facilities where controls for potential oxygen deficiency hazards (ODH) are implemented are listed in Table 3.2.4.b.

Table 3.2.4.b. Collider-Accelerator ODH Areas

ODH Area	**ODH Class**	**Main Hazard**
Collider Tunnel	0 (when gas < 50K)	Helium
Building 1002A	0 (when gas < 50K)	Helium
Building 1004B	0 (when gas < 50K)	Helium
Building 1006B	0 (when gas < 50K)	Helium and Nitrogen
Building 1008B	0 (when gas < 50K)	Helium
Building 1010A	0 (when gas < 50K)	Helium
Building 1012A	0 (when gas < 50K)	Helium
Building 1005R	0 (when gas < 50K) 1 (when liquid in pots)	Helium
Building 1005H	0 (main He storage or LN2 source not isolated and LOTO from building)	Helium
Building 1005E (west)	0 (main He storage or LN2 source not isolated and LOTO from building)	Helium and Nitrogen
Building 919 (g-2)		
919 Compressor Room	0 (when operating)	Helium
919G Refrigerator Room	1 (when operating)	Helium
919 High Bay	0 (when operating)	Helium and Nitrogen
Tandem (901A)		
MP-6 and MP7 Pits	0	Sulfur Hexafluoride
Mechanical Equipment Rm.	0	Sulfur Hexafluoride
Electrical Equipment Rm.	0	Sulfur Hexafluoride
Building Equipment Rm.	0	Sulfur Hexafluoride

3.2.5. Design Criteria and As-Built Characteristics for Cryogenic Systems

3.2.5.1. Hydrogen Systems

The ion accelerators on occasion use fixed targets of up to 3 liters of liquid hydrogen. The cryogenic target enclosures are sufficient to contain and vent the hydrogen should target containment fail. Automatic fail-safe venting would occur should a fire break out near the target, should a power failure occur or should a leak develop at the target or target vacuum. Safety review of the design and a design analysis for hazards are performed for each target, before use. A cryogenic target watch is assigned round-the-clock during operations.

The refrigerated hydrogen/deuterium targets are normally located in Building 912. The targets are located in secondary beam lines typically upstream of spectrometer magnets. The support stands for targets generally allow them to move several feet out of the beam. Target controls, monitoring and hydrogen detection is located downstream typically at the downstream side of the dump shield for the secondary beam line. Dump shields for these beams are typically eight-foot high, four-foot thick concrete blocks.

Targets typically contain 2 to 3 liters of liquid hydrogen or 1 to 2 liters of liquid deuterium. The target vessels have upstream and downstream windows that are typically 6 inches in diameter and constructed of 0.006-inch thick aluminum epoxy laminated with typically 0.01-inch thick Kevlar mesh.

Targets are surrounded by Herculite and aluminum sheet metal enclosures with 6-mil Mylar windows for the experimental beam. The enclosure allows air to be drawn past the target equipment and vented into the low-pressure target vent system. The enclosure is designed to contain the hydrogen or deuterium in the event of a total failure of the target system. The electrical equipment inside enclosures meets Class I Division II standards in the National Electric Code for electrical circuits in explosive atmospheres.

3.2.5.2. Helium and Nitrogen Systems

3.2.5.2.1.General Design Criteria

The cryogenic systems are designed with due consideration to the inputs indicated in Table 3.2.5.2.1. Because of the nature of these systems, the mechanical design is most heavily influenced by the ASME Boiler and Pressure Vessel Code, Section VIII and the ASME Refinery Piping Code, B31.3-1990. Design, fabrication and testing were performed in accordance with these codes. Proprietary computer codes were used for stress calculations to aid design compliance with the codes. For example, engineering codes such as ANSYS®, LSDYNA-3D®, CODECALC® or COMPRESS®. These are pressure vessel analysis and design programs developed to evaluate pressure vessel components according to the current requirements of Section VIII of the ASME Boiler and Pressure Vessel Code.

All stress calculations have an independent engineering check.

Table 3.2.5.2.1 Application of Design Standards for Cryogenic Systems at RHIC

Application	Design Standards
Pressure Vessel Design, Fabrication and Testing	ASME Boiler and Pressure Vessel Code, Section VIII ANSI Standard B31.1, Power Piping ASME Chemical Plant and Petroleum Refinery Piping Code, B 31.3-1990
Welding Procedures	ASME Boiler and Pressure Vessel Code, Section IX
All Bellows and Expansion Joint Design	EJMA Code, Expansion Joint Manufacturers' Association
Gas and Liquid Storage Tank and Vessel Design and Relief Valve Design	CGA S-1.3-1980, Pressure Relief Device Standards, Part 3-Compressed Gas Storage Containers

Where vessels or pipes are operating at cryogenic temperatures, the material used is chosen to retain ductility at cryogenic temperatures. Cracks or other flaws that might somehow be initiated do not propagate to catastrophic size because of the material ductility, and because leaks significant enough to degrade insulating vacuum would increase the refrigerator heat load and result in an aborted run.

Complete and accurate Piping and Instrumentation Drawings (P&IDS) have been prepared for all cryogenic systems. The Collider-Accelerator Department maintains the files for the P&IDS. These records are changed only by means of Engineering Change Requests/Notices (ECR/ECN), which are part of the formal configuration-control process. No changes, except in emergencies, are made in the equipment and piping shown on these drawings until an ECR/ECN has been issued approving said change.

3.2.5.2.2. As-Built Characteristics for Cryogenic Systems

Refrigeration to provide 4-degree Kelvin supercritical helium gas required for RHIC is produced by the 25-kW helium refrigerator. The refrigerator is housed in two structures. The helium is distributed by means of piping and valve boxes, both of which are vacuum insulated, plus ancillary warm piping and valves. This piping system carries the helium to and from the main refrigerator passing out-of-doors, into the RHIC Tunnel, where it connects to the superconducting magnets, and into the six service buildings located near the six experimental areas around the RHIC Ring. An inventory of cryogenic gases, by location, is shown in Table 3.2.5.2.2.

The numbers in the last column in Table 3.2.5.2.2 reflect the maximum that any portion of the cryogenic system could hold while the cryogenic system is operating. That is, running the RHIC rings at maximum operating pressure, having full storage tanks, and having full pots in the refrigerator. These maximum numbers are not normal operations but could possibly be achieved. The C-A Department does not have enough helium gas on-hand for the entire RHIC cryogenic system to operate at these conditions simultaneously. Thus, the maximum numbers reflect the maximum that could be in any portion of the system (RHIC rings, tanks, etc.) at any one time.

Table 3.2.5.2.2 Helium Inventory and Location, Thousands of Cubic Feet

Volume of Vessel	Location	Inventory During Shutdown	Inventory Normal Operation	Inventory Maximum Operation
	OUT-OF-DOORS			
8	Compressor Buffer Tanks	8	18	150
160	RHIC Gas Storage Area	3100	600	2693
1	Outdoor VacJac Piping	1	452	543
4	30,000 gallon LHe Storage	2759	700	2759
	Total	5867	1770	6145
	COMPRESSOR BUILDING			
4	Compressor System	4	48	53
	Total	4	48	53
	CRYOGENIC BUILDING			
0.2	Cold Box #l	0.24	5	6
0.2	Cold Box #2	0.24	1	6
0.2	Cold Box #3	0.24	12	13
0.2	Cold Box #4	0.24	80	88
0.2	Cold Box #5	0.24	705	780
0.2	Other	0.24	75	28
	Total	1.44	878	921
	TUNNEL			
0.9	Sextant 1	1.0	540	650
0.9	Sextant 3	1.0	540	650
0.9	Sextant 5	1.0	540	650
0.9	Sextant 7	1.0	540	650
0.9	Sextant 9	1.0	540	650
0.9	Sextant 11	1.0	540	650
	Total	6.0	3240	3900
	SERVICE BUILDINGS			
1.7	2 o’clock	2	50	60
1.7	4 o’clock	2	50	60
1.7	6 o’clock	2	50	60
1.7	8 o’clock	2	50	60
1.7	10 o’clock	2	50	60
1.7	12 o’clock	2	50	60
	Total	12	300	360
	Grand Total	5890	6236	

The Cryogenic Building 1005R is a high bay, steel frame, masonry building of approximately 7,200 square feet, with a volume of about 240,000 cubic feet, and is located immediately west of, and contiguous to, the Collider Center, Building 1005S. Though contiguous, the two buildings are structurally separate to insure acceptable acoustic levels in the Collider Center. The Cryogenic Building includes an 18-foot by 50-foot truck service platform. Access is through a 12-foot roll-up door. The exterior of the building is comprised of concrete block with five, approximately 16 foot square, openings on the north side through which the Cold Boxes were installed. These openings were then sealed to the vacuum tanks of the Cold Boxes.

The Compressor Building 1005H is a one story, high bay, similar in construction to the Cryogenic Building. It is approximately 10,800 square feet in floor area with a volume of about 200,000 cubic feet. It houses the helium compressors and their associated equipment. It is located just to the northwest of the Cryogenic Building.

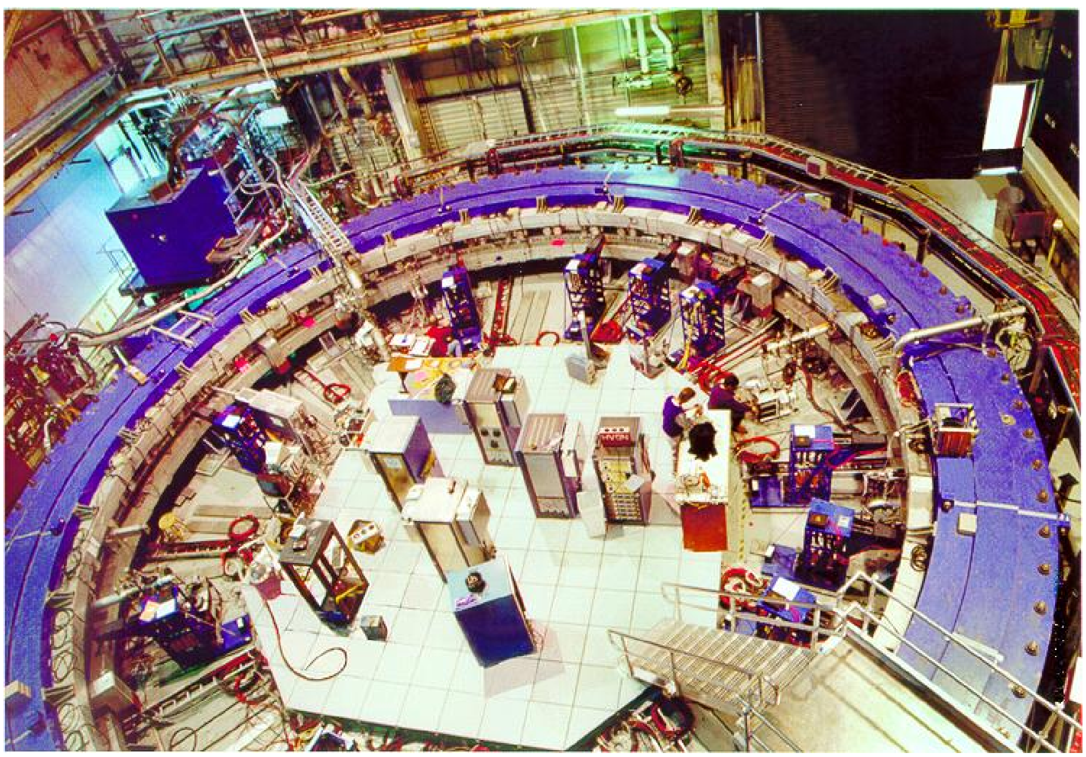
The six Service Buildings are metal frame, pre-engineered structures. The volume of these buildings varies from 75,000 to 113,000 cubic feet. Two Valve Boxes, one for each ring, are located in each Service Building. In addition, the Main Ring magnet power supplies are located in these buildings with their ancillary equipment. The six o'clock Service Building 1006B is also the location for a 700-W Helium Refrigerator, which typically operates only when the main 25 kW Helium Refrigerator is shutdown.

The Refrigerator and Compressor Buildings and the equipment located in them were reviewed by the BNL Cryogenic Safety Committee before the acceptance tests for the equipment were run. Approval for operation was received in 1984.

The Cryogenic Control Room is located in the Collider Center, Building 1005-S. A description of the control system may be found in the RHIC Design Manual.

The g-2 magnet in Building 919 is superconducting and requires liquid helium. The 1.451 T magnetic field of the magnet is used to constrain 3.094 GeV/c muons to move in a circle with a central orbit radius of 7.112 m. The muon storage region itself has a cross-sectional diameter of 9 cm. A photograph of the magnet is shown in Figure 3.2.5.2.2.

Figure 3.2.5.2.2 Picture of the g-2 Superconducting Magnet



The g-2 cryogenic system provides cooling for the g-2 superconducting magnets so that their operating temperature is less than the critical temperature of the superconductor with some safety margin.

The g-2 cryogenic system is divided into two parts. They are 1) the helium refrigerator and helium compressor system including the helium make up and recovery system, and 2) the control dewar and cryogenic distribution system for the g-2 storage ring superconducting magnet system. The two parts of the g-2 system are connected by low temperature supply and return lines that go to and from the refrigerator with 300 ^{o}K helium supply and return lines from the compressor system.

The cool down of 6200 kg of the g-2 solenoid cold mass and the cryogenic distribution system takes about three weeks. An additional 12 hours is required to fill the 1000 liter control dewar with the g-2 refrigerator running through the g-2 cryogenic system. Once the solenoids and the control dewar are at their normal operating temperature of 4.5 ^{o}K, the inflector is cooled to 4.5 ^{o}K in less than one hour.

Two-phase helium flow is supplied to the magnets by the helium refrigerator. Two-phase cooling avoids the increase in temperature along the flow circuit found in supercritical or single-phase gas cooling circuits. The operating temperature of the magnets is close to the temperature of the helium in the control dewar, which is about 0.3 ^{o}K difference. An advantage of two-phase helium cooling in tubes for the g-2 magnets is that the amount of helium in direct contact with the magnet coil is limited to the helium within the g-2 coil cooling tube. This has positive safety implications for the magnets and their cryogenic vacuum vessels.

The g-2 refrigeration system is self-regulating and it maintains a constant liquid level in the control dewar unless there is a gas loss from the system. By using this approach, the refrigeration delivered to the load is proportional to the heat load into the g-2 cryogenic system. The control dewar acts as a buffer vessel that can provide additional cooling by using the liquid stored in the dewar during times when the thermal load exceeds the capacity of the refrigerator. The major disadvantage of forced-flow two-phase helium cooling is that stopping flow will stop cooling. Therefore, when the refrigerator stops operating, the magnet warms up. The g-2 system uses a control dewar with 1000 liter storage capacity that can be fed into the cooling flow circuit to provide about 30 minutes continuous cooling before the magnet temperature rises above the critical temperature of the superconductor. This provides a redundant source of liquid helium when there is an electrical power failure or some other problem that can shut off the refrigerator. There is enough liquid stored in the control dewar to permit one to discharge the solenoids without quenching them.

The g-2 cryogenic control system is distributed among three locations, the magnet ring hall, the compressor room and the refrigerator room. Computers using a commercial software package communicate with programmable logic controllers. The system is responsible for monitoring and controlling temperature sensors, pressure transducers and valves. The cryogenic control software provides operator interface, real-time supervisory control and data acquisition and logging in both graphic and text formats.

3.2.6. Design Criteria and As-Built Characteristics of the TVDG Gas System

In any large high-voltage equipment, the presence of extremely high potential gradients necessitates the use of an insulating medium for stable operation. For this reason, the high voltage structures of MP6 and MP7 are enclosed within large pressure vessels pressurized with insulating gas. These vessels are code stamped, meeting the ASME Boiler and Pressure Vessel Code, Section VIII, Division I, with a maximum rated pressure of 300 psig. Overpressure relief valves rated at 250 psig are located on the main fill line and on each vessel.

Each of the Tandem Van de Graaff accelerators, MP6 are MP7, are located in Building 901A. Each accelerator pressure vessel (11,250 ft^3) contains an insulating gas mixture at a nominal operating pressure of about 12 atmospheres. The gas mixture is composed of roughly 45% SF, 45% N_2, 5% CO_2 and 5% O. The gas mixture is not routinely released. The gas is scavenged down to a pressure of 1000 micron (1 torr) before backfilling the vessel with air to allow for personnel entry.

The Insulating Gas Storage Facility is located atop the hill, which rises north from the Building 901A roof and crests at Building 704. The structure is completely separate from the 901A structure. It consists of two opposing banks of high-pressure gas storage cylinders with an intervening concrete structure allowing access to the gas system. Each bank consists of three buried layers of cylinders separated by earth, with the upper layer 42 inches below grade.

The gas handling system is capable of moving large amounts of insulating gas safely and quickly between the accelerator pressure vessels and the insulating gas storage facility. In order to permit opening and closing of an accelerator pressure vessel in a single shift, the system can handle all phases of gas pumping in four hours. To avoid temperature shocking the glass and metal accelerator tubes and column structures within the pressure vessels the maximum rate of temperature change is 10 ^{o}F/hr, with a maximum gradient along the accelerator structures of 10°F. To this end, one external and two internal heat exchangers for each accelerator provide heating or cooling to the insulating gas as necessary. Automatic temperature controllers are used to modulate hot and cold-water flow to these heat exchangers. Based on tests, the low thermal conductivity and high heat capacity of these structures are enough to maintain temperatures within the temperature specifications. Therefore, the use of the temperature regulating system is standard procedure, and is not a requirement for safety.

The two major considerations for personnel safety are the physical hazards associated with a rupture of a system component due to over-pressure, and the oxygen-deficiency hazard (ODH) posed by the insulating gas. To minimize these hazards, the gas handling system includes a variety of safety features. These include: 1) written procedures for all phases of gas transferals, 2) automatic pressure control, 3) flow-control valves at key points, 4) the use of over-pressure relief devices throughout the system, 4) keyed locks and micro-switches to ensure that a vessel is secured prior to pressurization and 6) ODH monitoring and alarms.

The relief valves are tested every five years. All accelerator-room relief valves discharge to their immediate locale. Mechanical-equipment-room relief valves vent external to the building in order to eliminate areas at TVDG that have a potential to be greater than ODH Class 1. Automatic isolation ball valves and overpressure relief flanges are located at beam-line and accelerator penetrations to halt gas flow in the event of an accelerator tube rupture. The valves actuate upon loss of vacuum in the accelerator tubes. Overpressure relief flanges prevent pressurization of the beam-lines while the ball valves are closing.

To alert personnel of an oxygen displacement hazard, fixed oxygen sensing and insulating gas detection equipment constantly monitor ambient conditions. In particular, an SF, detection system monitors the gas storage facility and various locations in the Accelerator Rooms with sensitivity adjustable down to 10 ppm. Oxygen monitors on both the main level and the pit level of the Accelerator Rooms and in the Mechanical Equipment Room alarm below 19.5%. Should any unusual levels of oxygen or SF_6, be detected, these systems will alert operations personnel immediately. An operator can then initiate emergency procedures in the OPM.

If the SF_6 alarm activates, then the situation is likely to be a minor gas leak, a maintenance problem rather than an emergency. After checking to ensure that there is no indication of oxygen deficiency, operators enter the affected area. As a precaution, they carry portable oxygen and halogen monitors and two-way radios while locating and isolating the leak. If a single oxygen-monitor alarms, with no other evidence of a gas leak, it is likely that the monitor is giving a false alarm and requires service. After activating a high-speed purge-ventilation-system and notifying the Local Emergency Coordinator, operators may enter the affected area, carrying the same safety equipment as for an SF, alarm. In each of the above cases, emergency responses are initiated if portable monitors indicate an oxygen deficiency.

If an oxygen monitor alarms along with an SF_6 monitor alarm, or an audible leak is heard or a second oxygen monitor alarms, then the situation is treated as an emergency and Laboratory Emergency Response personnel are notified immediately. The high-speed purge-ventilation is initiated and the Local Emergency Coordinator is notified. TVDG operators make an announcement over the PA system, and alert the MCR, and Plant Engineering that a dangerous asphyxiating condition may exist. Plant Engineering is notified due to possible accumulation of asphyxiating gas in the manholes in the area.

During the emergency, the building is evacuated. It is unlikely that individuals outside of the immediate area are at risk of asphyxiation. The building ventilation system does not circulate air from the Accelerator Rooms into the office and laboratory areas. Although there are some connections to low lying areas of the building via cable tray passageways and under doorways, it is expected that normal building ventilation combined with mixing with room air would prevent concentrations from reaching hazardous levels. The primary purpose of the building evacuation is to ensure that individuals do not enter affected areas and to avoid interference with emergency responders.

In certain applications, it has been shown that SF_6 can decompose in an electric discharge, producing toxic reactive compounds such as S_2F_{10}. There is no evidence that these compounds have been detected in harmful concentrations in the insulating gas of an accelerator. The activated alumina drying towers through which the insulating gas of the TVDG accelerators constantly circulates form effective scrubbers for these compounds. Independent documented toxicity tests of the gas mixture from the TVDG vessels have shown no evidence of toxicity.

3.2.7.Design Criteria and As-Built Characteristics of Shielding

3.2.7.1. Shielding Policy

The main features of this shielding policy are currently delineated in the Collider-Accelerator Department Operations Procedure Manual.[8, 9] The principal components of this

[8] http://www.agsrhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-12.PDF Procedure for Review of Collider-Accelerator Department Shielding Design

[9] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch08/08-13.PDF Collider-Accelerator Department Procedure for Shielding/Barrier Removal, Removal of Primary Area Beam Line Components, or Modifications

policy are reviewed here for completeness. The shielding policy is also summarized in Appendix 3 for easy reference.

The primary purpose of the shielding policy is to assure that all radiation related requirements and administrative control levels are satisfied. Specifically, the Collider-Accelerator Department's Radiation Safety Committee reviews facility-shielding configurations to assure:

- annual site-boundary dose equivalent is less than 5 mrem
- annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities is less than 25 mrem
- maximum dose equivalent to any area where access is not controlled is limited to less than 20 mrem during a fault condition[10]
- for continuously occupied locations, the dose equivalent rate is ALARA but in no case greater than 0.5 mrem in one hour or 20 mrem in one week
- dose equivalent rates where occupancy is not continuous is ALARA, but in no case exceeds 1 rem in one year for whole body radiation, or 3 rem in one year for the lens of the eye, or 10 rem in one year for any organ

In addition to review and approval by the Radiation Safety Committee, final shield drawings must be approved by the Radiation Safety Committee Chair or the ESHQ Associate Chair. Shield drawings are verified by comparing the drawing to the actual configuration.

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[10] During operation, the RHIC berm is a Controlled Area. However, the access road into RHIC is uncontrolled. The short uncontrolled portion of road atop the berm is protected by Chipmunk radiation monitors. This area is the single exception to the C-AD shielding policy for protection against faults, and maximum fault dose on the roadway is estimated to be less than 50 mrem if a highly unlikely point loss occurs at that location.

Radiation surveys and fault studies are conducted to verify the adequacy of any new or modified shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed by additional Collider-Accelerator Department procedures, which are not elaborated here.[11]

Any modifications to shielding configurations are likewise closely proscribed. Each Department accelerator or experimental area is assigned a liaison physicist and liaison engineer. The liaison physicist is responsible, in consultation with the Radiation Safety Committee (RSC) where appropriate, for determining safe conditions for any shielding modifications. The liaison engineer is responsible for ensuring that the safe conditions are met, for effecting any modification, and for notifying other responsible Collider-Accelerator Department personnel, including the Operations Coordinator, as well as experimenters both prior to and on completion of the modifications. Additional procedures exist to ensure that policy with respect to control of radioactive shielding is implemented, which are not elaborated here.

During the review, the RSC examines the layout of the facility, experimental area and/or the beam transport system. Possible radiation sources during fault conditions are examined. These possible sources include apertures, collimators, instrumentation, valves, magnets, targets, detectors and beam scraping in the beam transport pipe. Sources caused by improperly adjusted beam elements are also considered. Based on shielding and experimental requirements, the RSC then sets the normal operating parameters for the area into the Committee records. For example, the RSC can approve primary beam energy, particles per second on target and the target parameters such as beam spot size. The RSC also establishes the radiological classification of

[11] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-09.PDF Fault Study Procedure for Primary and Secondary Areas

areas outside of shielded areas that have dose rates above background; that is, they review and approve contiguous Radiation Areas and High Radiation Areas that result from beam operations. Area classifications are established for both normal and abnormal operating conditions.

3.2.7.2.Fault Studies

RSC representatives, liaison physicists and MCR operations staff perform fault studies in primary and secondary beam areas in order to verify the adequacy of shielding and radiological controls following a shielding modification. An RSC member or other knowledgeable person, e.g. liaison physicist, is assigned by the RSC to lead the fault study. Because the study may produce greater than routine levels of radiation, it often involves changing the state of a chipmunk radiation monitor from interlock to non-interlock mode via a local switch setting on the unit. This change requires RSC review and equivalent administrative controls must be in place until the study is over and the state of the radiation monitor is returned to normal.

At the start of study, a specific Fault Study Plan must be defined by the knowledgeable person specifically for the beam properties in the area. This plan must be reviewed and approved by the RSC. The end of study is part of the plan and occurs when the operators return to routine operating mode for the accelerator. Only qualified RCTs assist with the pulsed radiation surveys during the fault study.

Beam fault studies are conducted using the minimum beam intensity necessary to complete the study efficiently and they are consistent with ALARA practices. Any fault study requiring higher intensity than 10% of normal operating intensity must be reviewed and approved by the RSC. Beam not lost at the intended location(s) for the fault study is safely aborted, if practicable, at target stations, beam dumps or other acceptable locations. Area announcements over the PA are made before initiating the fault condition, and at the time that the fault study is completed. The beam is "ON" in the fault condition only as long as necessary for adequate survey measurements to be taken.

The survey team is informed of the expected exposures during the study based on the dose rate estimates provided in the Fault Study Plan. The survey team determines whether it is appropriate to participate based on their accumulated dose, and the dose estimates are used in the Radiation Work Permit issued for the study.

Before the fault conditions can be established, the appropriate locations for the desired fault study are swept. The vicinity of the fault study, including nearby potential beam loss locations, is posted by RCTs with signs and tape where appropriate.

Data for the fault study are entered in a designated fault study logbook for the area. Data includes location of loss, beam intensity and measured radiation levels. The RSC Chair must review the fault study results within a reasonable period to determine if changes to the shielding and/or area access requirements are necessary. That is, the RSC Chair must concur or disagree with the classification of the area indicated in Table 3.2.2.1 based on the results of the fault study.

3.2.7.3.Configuration Control of Shielding Drawings

The C-A Department RSC Chair and the C-A Department ESHQ Associate Chair must approve the shielding design. The record of approval can be part of RSC meeting minutes or a separate document signed by the RSC Chair and the ESHQ Associate Chair. The official shielding print is approved and assigned an identifying number in order to become a permanent record. The C-A RSC Chair files the minutes of the Committee review of the shielding design and approval, and provides the project engineer with a copy of the approval. Preparation, modification and issuance of engineering drawings are done in accordance with quality assurance procedures in OPM Chapter 13.[12]

3.2.7.4.Typical Earth Berm Shield

Figures 3.2.7.4.a and 3.2.7.4.b show typical earth berms used for shielding. These particular berms are for the Booster beam dump and the NSRL line (R line). The Booster beam dump also has a cap, which is seen in the picture. The photo of the new R-line berm (Figure 3.2.7.4.b) also shows the standard geo-membrane-type cap typically used for groundwater protection. Also visible are the ventilation shafts in the R-line berm. Since 2002, geo-membrane caps have been placed over new shield berms as they are constructed. More information on berm caps and the reasons for their use is provided in Section 3.2.7.7. An addition layer of soil is placed over the membrane to complete the berm. Earth berm shields and their caps are covered with grass to prevent erosion. Berm shields are inspected at the start-up and conclusion of each running period, which is typically twice per year. Soil erosion, tree or shrub penetration and cap integrity, where applicable, are the main reasons for inspections.

[12] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm Operations Procedure Manual

Figure 3.2.7.4.a Typical Earth Berm and Cap Used for Shielding, Booster Beam Dump

Figure 3.2.7.4.b Typical Earth Berm and Cap Used for Shielding, R Line (NSRL)

Figure 3.2.7.4.c shows the earth berm for the U line. Currently, there is no cap for the earth shield at the U line; however, experiments are restricted to low intensity and minimal beam losses such that rainwater leachate containing soil-activation products such as tritium will never exceed the Drinking Water Standard. Future experiments to be built in this area will require the addition of a soil cap. On the other hand, if rainwater percolates through the soil over the U line tunnel, then it would ultimately drain onto the supporting concrete pad and would join many thousands of gallons of storm water run-off entering the on-site recharge basin via the trench

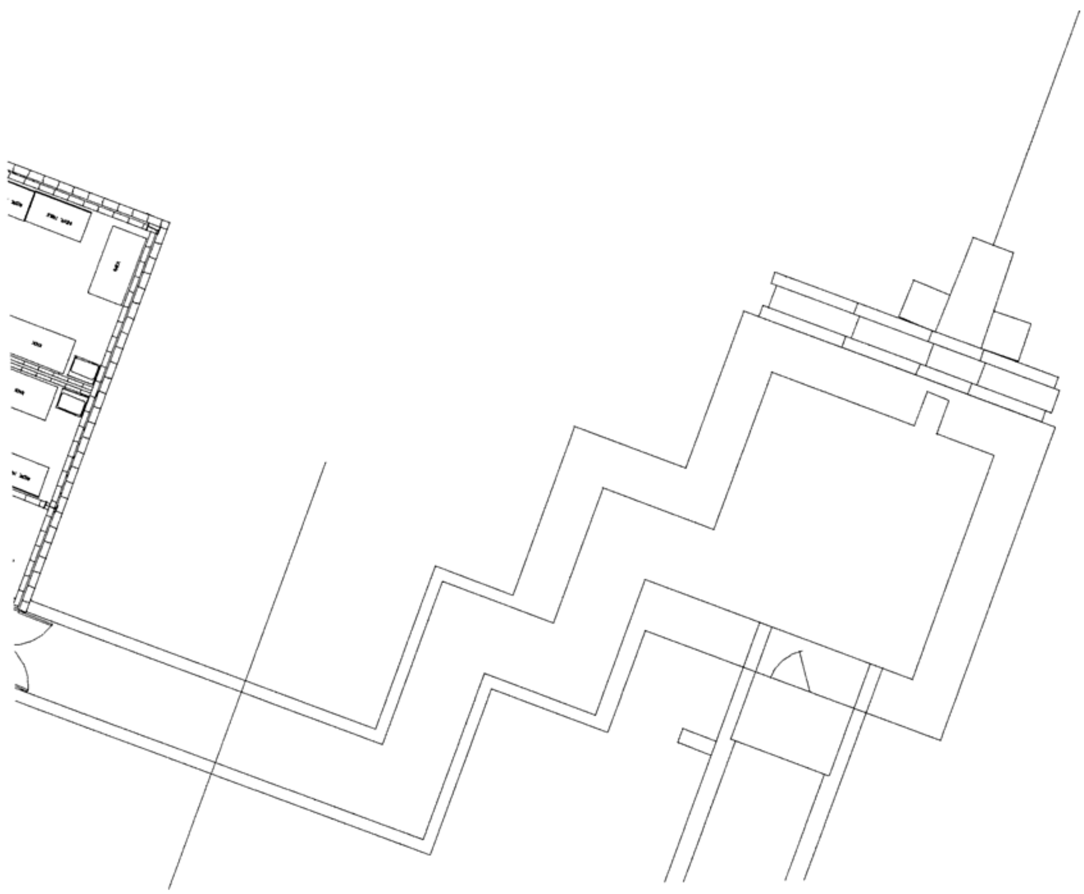
network in the apron, which is also visible in the photo of the U line. This runoff is routinely monitored for tritium concentrations at the recharge basin and discharges are at or near naturally occurring concentrations.

Figure 3.2.7.4.c Typical Earth Berm Used for Shielding, U Line

3.2.7.5.Typical Labyrinth Design

Figure 3.2.7.5 shows a typical labyrinth design. Multi-leg labyrinths are used to minimize routine radiation levels. Dose calculations for labyrinths are generally simulated by using the MCNPX code. The dose due to neutrons of energy less than 20 MeV is often calculated, since this is very nearly all the dose at the closest people should be when the beam is on at high-energy accelerators.

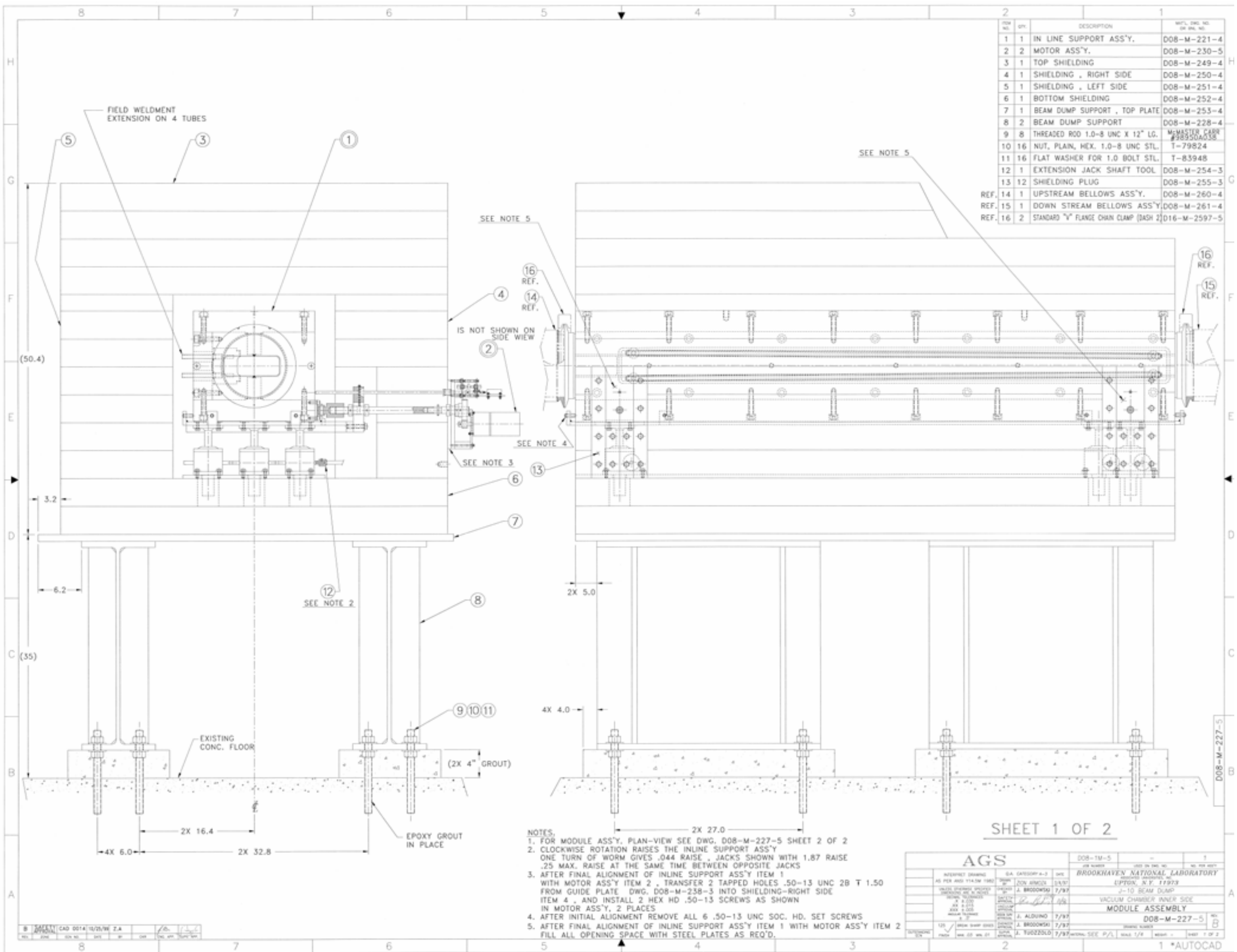
Figure 3.2.7.5 Typical Labyrinth Design



3.2.7.6.Typical Shielding for an Accelerator Collimator and Dump/Scraper

The J10 scraper in the AGS Ring is typical of a beam scraper in an accelerator (See Figure 3.2.7.6). It is designed to have 2 feet of iron around the beam impact point with in general 12 feet of drift space to the tunnel wall, which is on average 1-foot thick concrete. Typically, 24 GeV beam and 5% of the annual average beam intensity winds up in the scraper. The iron around the scraper minimizes the amount of secondary particles that escape into the soil shielding. In the case of the J10 scraper, 3 to 5 feet of concrete are buried in the soil berm around the scraper, which greatly reduces soil activation.

Figure 3.2.7.6 Drawing of J-10 Dump in AGS Showing Iron Shielding



3.2.7.7. Caps over Activated Soil Locations

When a high-energy particle interacts with matter, many secondary particles are emitted which could themselves have a high enough energy to produce additional particles when they interact, thus creating a nuclear particle cascade. Most high-energy secondary particles interact in the shielding around the targets. The materials used in the construction of the target areas are limited in number, the most important being iron, steel, copper, aluminum, concrete and earth. When a high-energy secondary particle, which is usually a neutron with energy between 20 MeV and 100 GeV, interacts in these materials, a variety of radioactive atoms is produced. The mass numbers of the radioactive atoms range from the mass number of the target-atom-plus-the-particle down to a mass number of three, which is tritium the radioactive atom with the smallest mass. Most of the radioactive atoms are very short-lived and decay back to stable atoms quickly. It is important to recognize that most of these manufactured radioactive atoms are deeply entrained in magnets and in concrete shielding. This is due to the penetrating ability of the high-energy secondary particles. These entrained radioactive atoms are not readily dispersible, even in a fire.

Some secondary radiation from proton interactions can penetrate the iron and concrete shielding around a target hall and interact with the nuclei of Si and O atoms present in nearby soil. The two most important long-lived radioactive species created by secondary radiation interactions in soil are 12.3-year ^{3}H, and 2.6-year ^{22}Na. Other short-lived radioactive atoms are produced but they decay quickly to stable atoms. If rainwater is allowed to infiltrate the activated soil shielding, the long-lived radioactive atoms can be leached from the soils and carried downward to the ground water. To prevent this leaching process, the soil shielding is capped by a water impermeable barrier. It is noted that all planned beam-loss areas such as beam dumps, beam stops and target caves at the C-A Department accelerators and experimental areas are protected from rainwater by roofs, concrete caps or geo-membrane caps. The caps are designed to meet requirements in SBMS, Design Practice for Known Beam-Loss Locations.

In accelerators, most shielding is ordinary earth and concrete. Iron is often used as beam-stop wherever space is at a premium. Because iron is denser than earth or concrete, iron greatly decreases the size of a beam dump. In one area, the C line, depleted uranium blocks were used in part of the beam dump. The use of uranium saved volume where space was limited. The uranium beam dump effectively absorbs muon radiation, which allows the beam dump to be shorter in length. However, uranium presents other hazards and a separate safety analysis was performed for this shielding application.[13] Subject to funding, these uranium shield blocks are scheduled to be removed and appropriately dispositioned in FY05.

A beam dump serves as the preferred repository for any beam that might be lost in the accelerators before reaching the experimental areas. Ideally, all residual radiation would be in the dump rather than being spread around other accelerator components. A beam dump in an accelerator is a solid block of metal, usually several feet thick. In Booster and AGS, the dump encircles the beam and has a opening through it to allow beam to pass through (see Figure 3.7.2.6). The upstream end of the dump has a protruding lip on the inside, which is used to "scrape" the beam, removing the outermost particles from the beam orbit. At RHIC, a fast-kicker magnet is used to kick the whole beam onto the face of the dump to give high efficiency

[13] Implementation Plan and Basis for Interim Operation with Preliminary Hazard Assessment for AGS Uranium Shield Block and Experiment 877 Uranium Calorimeters, Brookhaven National Laboratory, Associated Universities, Inc., Upton, New York 11973, August 3, 1993.

absorption of beam when required. The beam dump at RHIC is to the side of the circulating beam rather than encircling the beam; however, collimators, which encircle the beam, are used at separate locations to remove any halo of particles.

There are no beam dumps in the Linac, only beam stops. Typically, thick HDPE liners cover stops, dumps and collimators in order to shed rainwater away from potentially activated sections of soil shielding. The activated soil is predominantly forward of the absorber block or collimator due to the forward momentum of the secondary particles. A typical HDPE liner is shown in Figure 3.2.7.4.b.

The large angle of the Booster berm prevented the use of standard geo-membrane-type materials for groundwater protection at this location (see Figure 3.2.7.4.a). Therefore, a Gunite cap was installed and extends over an area of about 3000 ft^2 and is about 5-inches thick. Gunite is the best material for the cap because of ease of installation and high strength. Gunite strength approaches 5000 psi, which is characteristic of reinforced concrete. As an added feature, the Gunite was capped by EDPM rubber, which is standard roofing membrane. To ensure continued integrity of the Gunite, it is be inspected by the responsible C-AD Liaison Engineer every year.

Target caves house and shield the primary production targets in the fixed target experimental areas. Secondary particles, which are the focus of most experiments, are produced through interactions of the primary protons in target material. Targets are frequently made of metal by virtue of their refractory characteristics, thermal conductivity and high mass-density. A typical target is several hundred grams of platinum. About half the primary beam interacts in a target and virtually all the secondary particles produced in the target leave the target and interact elsewhere.

The target cave is the terminus of the primary beam transport for fixed target experiments. Beam is transported through a series of magnets providing control of the size of the beam and the beam direction. Beam interactions remote from the production target are minimized by confining the beam to a pipe evacuated of air. This beam pipe runs the entire length of the accelerator complex, through magnets and beam-line equipment. There are over six miles of evacuated beam pipe in use at the complex.

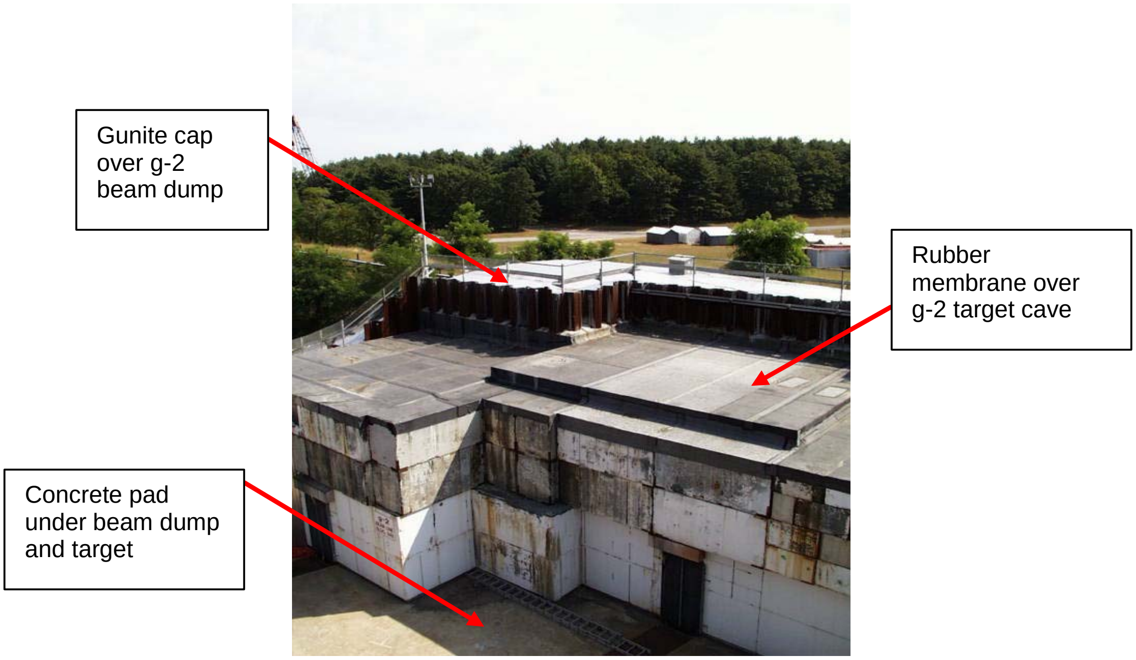
Target caves are constructed of heavy concrete and steel shielding and they have labyrinthine entry passages in order to prevent personnel exposure. The walls and floor of a target cave retain most of the radioactive atoms that are created by secondary particles emanating +from a target.

Figures 3.2.7.7.a, b and c show the roofed structures over the target caves. These roof structures are designed to shed rainwater to the paved areas that surround the experimental areas. This rainwater from the roofs flows directly to storm sewers and if shed to paved areas, to storm sewers located in paved areas and then into the recharge basin known as HN.

Figure 3.2.7.7.a Roof and Concrete Floor over Activated Soil Areas at Building 912

Figure 3.2.7.7.b Roof and Paved Area over Activated Soil Areas at Building 912

Figure 3.2.7.7.c Rubber Roof, Gunite and Paved Areas over Activated Soil Areas at g-2



Figures 3.2.7.7.d and e show the geo-membrane structures over potentially activated soil areas. These geo-membrane structures are designed to shed rainwater to the unaffected soil that surrounds the experimental areas.

Figure 3.2.7.7.d Geo-membrane Over Potentially Activated Soil Areas at NSRL

Figure 3.2.7.7.e Geo-membrane Over Potentially Activated Soil Areas at RHIC

Primary and secondary beam dumps are the sinks used to absorb the energy and concomitant radiation from beams that have completed their utility. The length and transverse dimensions of the dump are designed to assure that the radiation generated from a primary beam of 30-GeV protons is sufficiently attenuated. The iron beam dump for the g-2 experiment, for example, is 50 x 10 x 10 feet, and it sits on a 3-foot thick concrete pad. We note that the size of beam dumps is such that they entrain the bulk of radioactive atoms created because of stopping primary particles and most of their secondaries. A cap over a primary beam dump is required if significant secondary radiation reaches soil to create activation. The threshold for a cap is any potential to exceed 5% of the Drinking Water Standard in rainwater leachate that goes to groundwater. See Figure 3.2.7.7.c for an example of a cap over the external g-2 beam dump.

3.2.7.7.1. Activated Soil Locations

The Linac injects protons into the Booster Ring and into the Brookhaven Linac Isotopes Producer (BLIP). The BLIP is under the purview of the BNL Medical Department and soil activation for the BLIP facility is estimated in Reference 14.

Detailed computation of total soil radioactivity near beam stops, beam dumps and targets is difficult. Calculations and soil measurements are on going and the Collider-Accelerator Department is developing a detailed archive of information that will document the size and shape of all soil activation areas. The archive project is anticipated to be complete in 2005 (see Table 3.2.7.7.1). Note the Table refers to Fact Sheets and Map References that will be developed as part of the project.

[14] "Soil Activation Computation for BLIP," BNL Memorandum, J. Alessi, E. Lessard, and L. Mausner, to P. Paul, AGS Department, Brookhaven National Laboratory, Upton, New York 11973, May 7, 1998.

Table 3.2.7.7.1 Potential Activated Soil Shielding Areas at Accelerator Facilities Prioritization of Fact Sheet Development

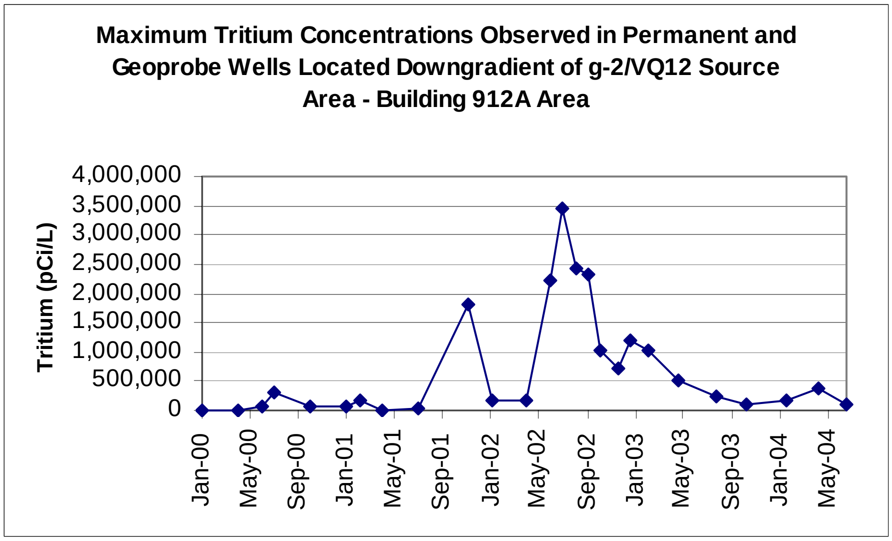
Fact Sheet	Activation Area	Responsible Department	Map Reference
1	g-2 VQ-12 source area	C-AD	22
2	g-2 V-line target	C-AD	20
3	g-2 V-line dump	C-AD	21
4	Building 912 – A target	C-AD	8
5	Building 912 – A dump	C-AD	9
6	Building 912 – B target	C-AD	10
7	Building 912 – B5 target	C-AD	11
8	Building 912 – B dump	C-AD	12
9	Building 912 – C target	C-AD	13
10	Building 912 – C3 target	C-AD	14
11	Building 912 – C1-C3 split	C-AD	15
12	Building 912 – C3C1, C1Q4	C-AD	16
13	Building 912 – C dump	C-AD	17
14	Building 912 – D target	C-AD	18
15	Building 912 – D dump	C-AD	19
16	AGS Ring – A10 fast beam	C-AD	25
17	AGS Ring – A20 200 MeV inflector	C-AD	26
18	AGS Ring – B10; near old HITL-2 house	C-AD	27
19	AGS Ring – F5 septum	C-AD	28
20	AGS Ring – F10 septum	C-AD	29
21	AGS Ring – F20 internal targets	C-AD	30
22	AGS Ring – G10 internal target	C-AD	48
23	AGS Ring – I10 area	C-AD	31
24	AGS Ring - I13 internal target	C-AD	49
25	AGS Ring – L20 injection (old and new)	C-AD	32
26	AGS Ring – Former H Area	C-AD	33
27	AGS Ring – Former E20 catcher	C-AD	34
28	AGS Ring – J10 catcher	C-AD	35
29	AGS Booster – old dump	C-AD	36
30	AGS Booster – new dump	C-AD	37
31	BTA Extraction (Building 914)	C-AD	45
32	BLIP target	Medical	38
33	BLIP spur	C-AD	39
34	LINAC Stop A	C-AD	40
35	LINAC Stop B	C-AD	41
36	LINAC Stop C	C-AD	42
37	LINAC to Booster transition (EBIS)	C-AD	43
38	HEBT stop	C-AD	44
39	Building 927 – Former U-line target	C-AD	23
40	Building 927 – Former U-line dump	C-AD	24
41	RHIC Y dump	C-AD	1
42	RHIC Blue-line dump	C-AD	2
43	RHIC Yellow-line dump	C-AD	3
44	RHIC Blue-line collimators – Sector 8	C-AD	4
45	RHIC Yellow-line collimators – Sector 7	C-AD	5
46	NSRL target	C-AD	6
47	NSRL dump	C-AD	7
48	Building 937 - Rad Effects Facility	EENS	46
49	Building 939 – NBTF	EENS	47

As an example of the Fact Sheets under development, a brief set of facts is listed here for the g-2 area; specifically, for the area near the VQ-12 magnet, which is a quadrupole magnet just before the V target in the fast beam experimental area.

The VQ-12 magnet was struck by significant amounts of proton beam for several years in the late 1990s. This beam loss was not anticipated and C-AD has subsequently taken measures to prevent unintended beam losses in the future. The secondary radiation from proton interactions on the magnet iron penetrated the minimal amount of concrete shielding surrounding the VQ-12 magnet and interacted with the nuclei of Si and O atoms present in nearby soil. The two most important long-lived radioactive species created by secondary radiation interactions in soil at the VQ-12 area were 12.3-year ^{3}H, and 2.6-year ^{22}Na. Initially the VQ-12 area was not capped, rainwater infiltrated the activated soil shielding, and tritium atoms leached from the soils and were carried downward to the ground water. To prevent this leaching process, the soil shielding was capped by a water impermeable barrier in December 1999.

Figure 3.2.7.7.1.a shows the tritium concentrations in groundwater that were created from this event. This tritium plume is monitored and will be monitored for the next 20 to 25 years, or until the tritium concentrations dissipate below levels of concern. Studies and calculations show the plume is very narrow and cigar shaped, and it not expected to cause tritium concentrations above the Drinking Water Standard in offsite or onsite supply wells.

Figure 3.2.7.7.1.a Graph Showing Tritium Concentration in Groundwater Monitoring Wells



In order to define the area of activation near VQ-12, one must know energy and angular distribution of the primary and secondary radiation. The amount of beam lost on the magnet must also be known. Additionally, the fluence of secondary radiation penetrating to soil varies as a function of shape, thickness and type of materials around the magnet.

In 1989, detailed computations of soil activation near a prototypical design of the g-2 target and beam dump were performed and caps were placed accordingly.[15] However, ten years later tritium and sodium-22 were detected in groundwater monitoring wells. In response, the C-AD investigated source of the tritium and initially performed detailed radiation surveys of the V line and found the VQ-12 magnet was 3 rem/h at contact on its upstream end and 1.5 rem/hr on its downstream side. This residual radiation observed at the VQ-12 was not expected. Other magnets in the V line had much lower radiation levels; about 0.01 rem/h. Secondary particles

[15] D. Beavis, "Soil Me: Soil Activation Estimates for the g-2 Target Area and Beam Dump," AGS EP&S Technical Note 135, AGS Department, Brookhaven National Laboratory, Upton, New York 11973, December 5, 1989.

created at the VQ-12 magnet were estimated (calculated) to cause activation in nearby soil shielding within a radius of 30 feet or more. Based on the radiation level on the VQ-12 magnet, it was determined that as much as 15 percent of the beam was lost at this point in the V line and a detailed assessment of the soil activation in this area commenced.

To define the activation zone near the VQ-12 magnet, soil samples were taken in November 1999. The results indicated a total activity of sodium-22 of as much as 400 mCi. Based on the ratio of sodium-22 to tritium production in soils, this implied that more than 130 mCi of tritium were created in soil in this region.

Because the soil shielding around the VQ-12 area was not protected by a cap, tritium was able to move into the vadose zone and groundwater via rainwater that percolated through the activated soil. After the cap was installed, C-AD staff reviewed records on operational run times and beam losses to calculate the amount of radioactivity that was produced in the soils. A cap over VQ-12 area was installed in mid December 1999 and from that point on, tritium accumulated under the cap until the g-2 experiment ceased operations in late April 2001. Although the cap has been effective in preventing the continued leaching of tritium from the activated soils, tritium that was transported close to water table prior to capping continues to be released to the groundwater during annual fluctuation of the position of the water table (see Figure 3.2.7.7.1.a). The highest tritium concentrations were observed in July 2002, when concentrations reached 3.4 M pCi/L.

The zones of activation were determined and mapped (see Figures 3.2.7.7.1.b, c and d). Soils having a tritium concentration of approximately $>10^{-10}$ curies per cubic centimeter are of particular concern because if the cap were to fail and one year's average rainfall was able to leach through these soils, tritium concentrations in the leachate could exceed the 20,000 pCi/L drinking water standard. A comparison of the position of the cap to the calculated zone of activation suggests that the Gunite cap, and concrete pad on which the beam line was constructed, is adequately protecting the soils containing the highest levels of radioactivity.

Based on the g-2 experience, BNL developed a conservative standard for capping activated soil areas in order to prevent further contamination of the ground water. BNL's new beam-line design criteria calls for the capping of any activated soil area where potential leachate could contain tritium at concentrations greater than five percent of the Drinking Water Standard (>1,000 pCi/L for tritium). These criteria are described in the Accelerator Safety Subject Area (BNL, 2000). Because of this new standard, the C-A Department undertook the project to define and archive the facts regarding known beam loss locations. Because the standard calls for a cap at 20 times less than the Drinking Water Standard, the C-A Department anticipates that as the study continues, the need for additional caps may be identified.

Figure 3.2.7.7.1.b Map Showing Lines of Cross Section Through the VQ-12 Source Area

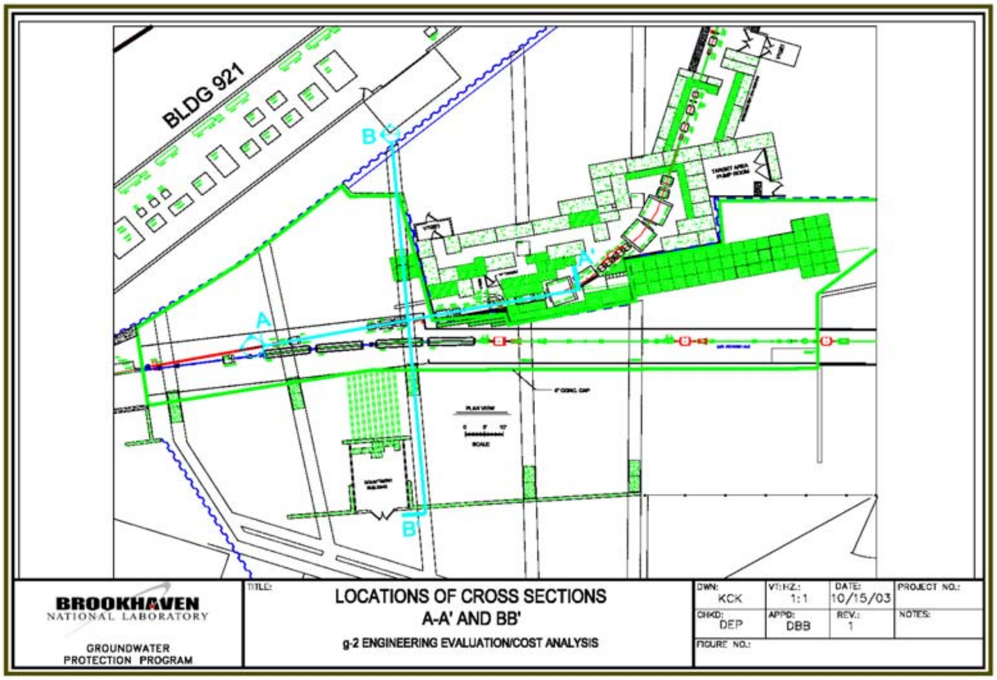


Figure 3.2.7.7.1.c North-South Cross Section A-A' which Runs Along the g-2 Beam Line

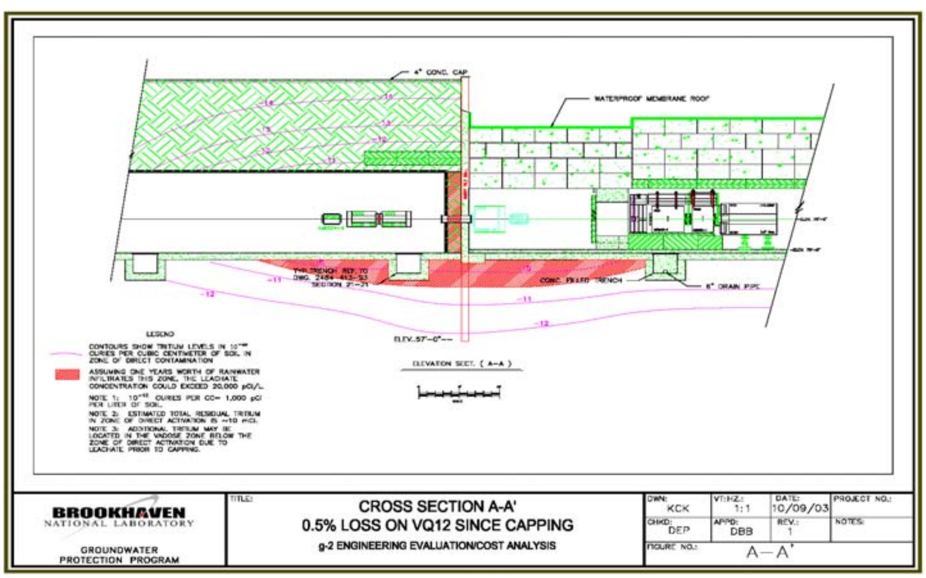
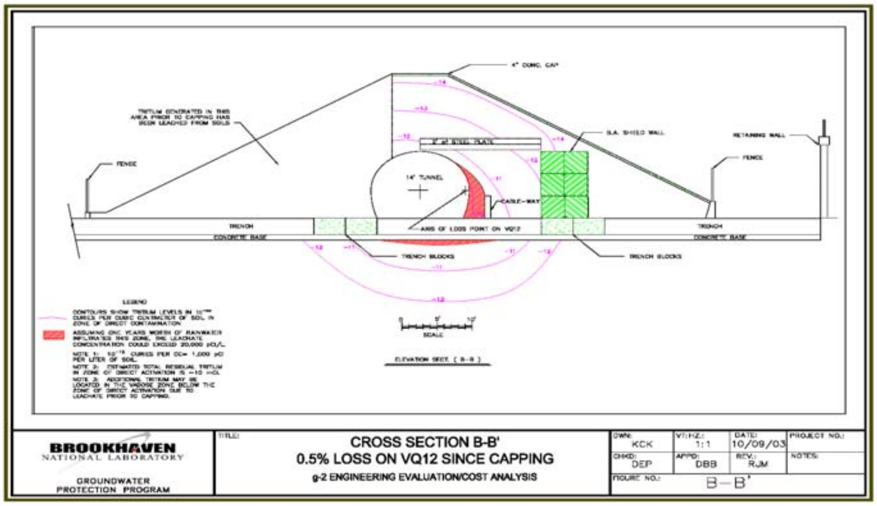


Figure 3.2.7.7.1.d East-West Cross Section B-B' Immediately South of the VQ-12 Magnet



3.2.7.8.Typical Block House Design for Fixed Targets

Figures 3.2.7.8.a and 3.2.7.8.b show a typical blockhouse used to shield high-intensity proton targets. This blockhouse was designed for the V Target. On the west side of the g-2 target there is the equivalent of 4 feet of iron that was placed to reduce the residual radiation level in aisle way inside the blockhouse. On the east side is 4 feet of iron and the U line tunnel. Four and a half feet of heavy concrete is placed below target down to floor level and 3 feet of concrete was placed on either side of the target but in a trench below floor level.

Other blockhouses at the C-A Department are further enclosed by larger buildings such as Building 912 or Building 956. See Figure 3.2.7.8.c for a view of the planned blockhouse for the KOPIO experiment in Building 912. The concrete blocks attenuate the radiation so that sky-shine radiation and direct radiation are within ALARA guidelines.

Figure 3.2.7.8.a Blockhouse Used to Attenuate Radiation

Figure 3.2.7.8.b Plan View of Blockhouse Used to Attenuate Radiation

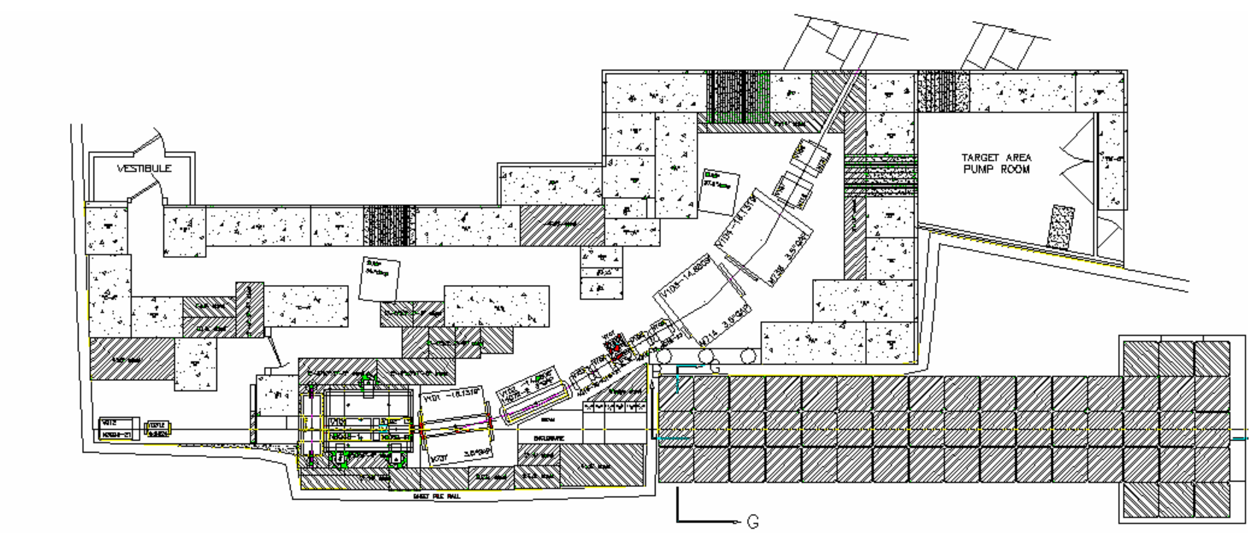
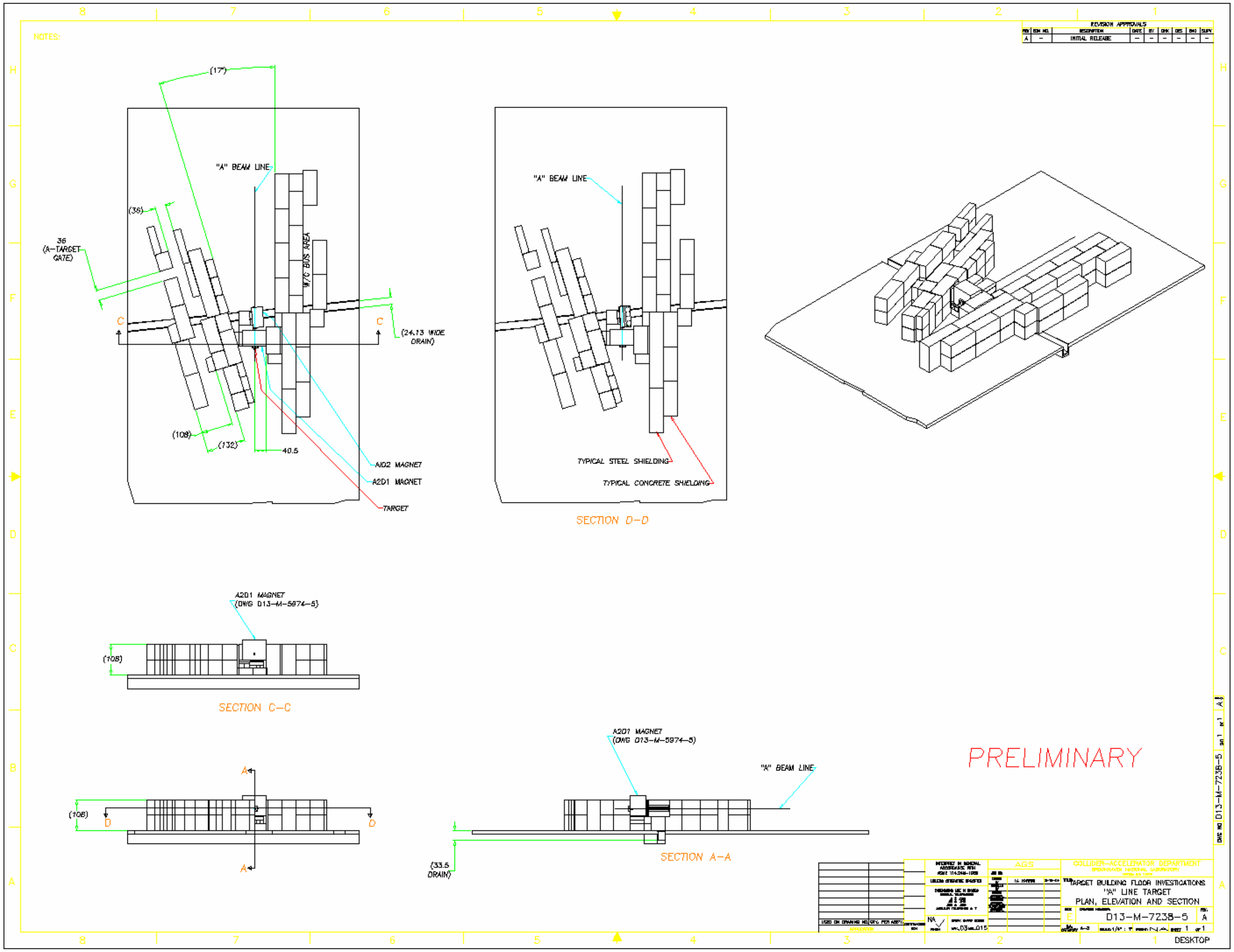


Figure 3.2.7.8.c Views of Blockhouse Used to Attenuate Radiation in A Line in Building 912



3.2.7.9. Typical Beam Dump and Re-Entrant Cavity in Experimental Areas

Beam dumps are the sinks used to absorb the energy and concomitant radiation from beams that have completed their utility. These dumps are typically made of ilmenite-loaded concrete, occasionally steel. See Figure 3.2.7.9.a for a drawing of the steel dump used for high-intensity proton running in the V line. The design often incorporates a recessed entry area, or reentrant cavity, which greatly reduces radiation shine perpendicular to the direction of the incident beam on the face of the dump. See Figure 3.2.7.9.b for an example of a re-entrant cavity at NSRL. The length and transverse dimensions of the beam dump are designed to assure that the radiation generated is sufficiently attenuated.

Beam dumps for high intensity protons may handle beam intensities up to the full capacity of the AGS, entailing an average energy dissipation of up to 90 kW for the SEB. Secondary dumps terminate a relatively small-analyzed beam of particles from a production target. Since analysis entails selection of a specific charge, or charge-to-mass ratio, and momentum bite of the total flux of secondary particles, the 'selected' secondary beam is orders of magnitude lower in intensity, and often lower in energy, than the primary beam, with consequently smaller beam dump dimensions.

Accumulation over time of residual radiation in beam dumps is a significant design consideration. Exposure levels of the order of tens of rem/h are common for high intensity proton beam dumps at the onset of shutdown, requiring attention to the reliability and maintainability of any nearby components.

Figure 3.2.7.9.a Plan View of V Blockhouse Showing 50-Foot Iron Beam Dump

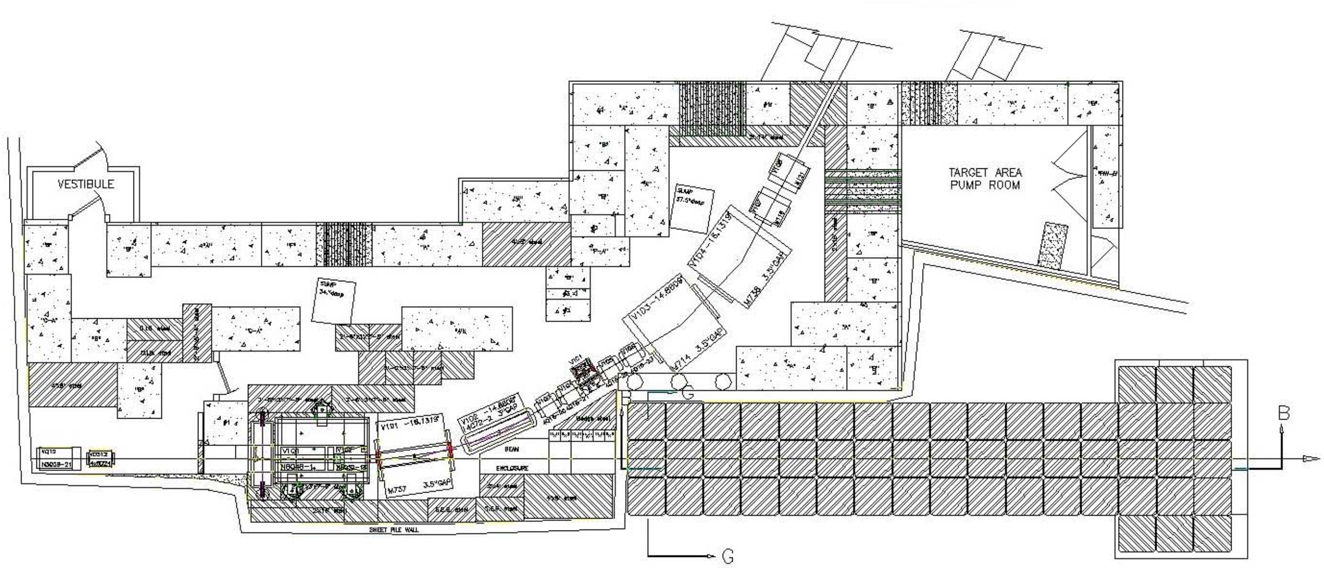


Figure 3.2.7.9.b Side View of V Beam Dump Showing Re-Entrant Cavity

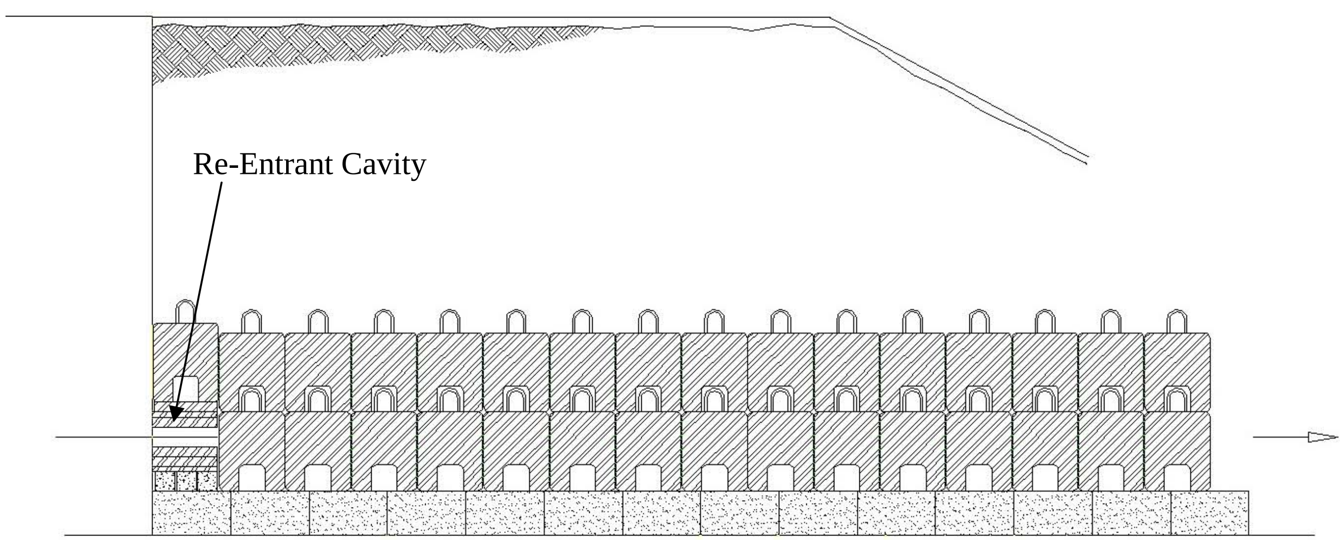
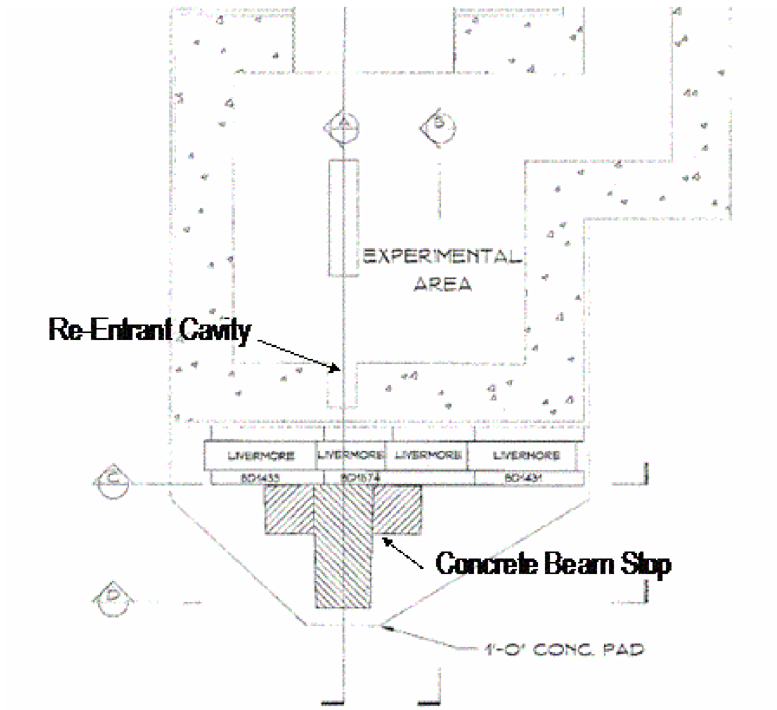


Figure 3.2.7.9.c Re-Entrant Cavity at the NSRL Beam Dump



3.2.7.10.Typical Shield Wall at a Collider Experiment

The area and height of the IRs varies. Most locations are equipped with overhead cranes that have direct access from grade. The six and eight o'clock areas have an assembly building that leads into an IR. Concrete shield walls separate these areas during the running period. The removable walls of IRs are composed of light concrete blocks. When the Collider is circulating beam, 5.5-foot thick blocks are used to form a shield wall in the IR separating it from the assembly building. See Figure 3.2.7.10.

Generally, movable shield block walls incorporate a small movable plug for personnel access, an emergency escape labyrinth and a larger movable door to allow movement of the large elements of the detector between the IR and the assembly area.

Figure 3.2.7.10 Shield Wall Enclosure at the STAR Experimental Hall

3.2.8. Design Criteria and As-Built Characteristics of Power Distribution

3.2.8.1. Substations and Transformer Yards

Standards and requirements that relate to design of substations and transformer yards are National Electrical Code, National Electrical Safety Code, National Fire Prevention Association standards, Institute for Electrical and Electronic Engineers standards, OSHA requirements, EPA requirements, National Electrical Manufacturers Association standards, Illumination Engineers Society standards, and standards developed by the American National Standards Institute.

The potential hazards associated with substations and transformer yards are electric shock, electrical short, arc-blast, oil spill, fire and clean waste disposal. Training, routine inspection, routine maintenance, personal protective equipment, secondary containment and trap rock to suppress fire are used to mitigate these hazards. Proper fuse ratings, circuit breaker settings and set points are selected to coordinate protection against faults and over loads. The nominal ambient operating temperature limit is 40 ^{o}C, and where necessary internal heaters are provided for cold temperatures. Supporting systems include batteries, the power-monitoring system and the oil/water separation weir.

A routine inspection schedule for substations and transformer yards is maintained by plant engineering, and routine maintenance is monitored by C-A Department. Maintenance procedures follow industry standards. Operational personnel need electrical safety training, and staff from Plant Engineering responds to emergencies using their standard practices.

Normal power from the power distribution system is not required for safety systems; however, the emergency power system is needed for systems that maintain property protection or prevent property loss such as cryogenic controls.

Circuit breakers are typically tested every three years. Presently, the substations are on a 2-month cycle for inspection and 2-year cycle for maintenance and testing. Comprehensive oil testing is on a three to six year testing cycle unless test results require more frequent testing per standards.

In order to minimize hazards, the transformer tanks contain mineral or silicon oil. Handling of oil is by line crew or outside oil vendor. No oil is discharged intentionally. Bi-monthly inspections of the substation are performed looking for oil leaks or spills. If transformer oil reaches soil or trap rock, the soil and rock are remove and put in containers for disposal. Industry standards are used for handling oil and oil waste.

3.2.8.2.Power Distribution

Standards and requirements that relate to design of power distribution are National Electrical Code, National Electrical Safety Code, National Fire Prevention Association standards, Institute for Electrical and Electronic Engineers standards, OSHA requirements, EPA requirements, National Electrical Manufacturers Association standards, Illumination Engineers Society standards, and standards developed by the American National Standards Institute.

The potential hazards include electric shock, electrical short, arc-blast, fire and oil spill from diesel generator tanks. Training, routine inspection, routine maintenance and personal protective equipment mitigate these hazards. Proper fuse ratings, circuit breaker settings and set points are selected to coordinate protection against faults and over loads. The nominal ambient operating temperature limit is 40 ^{o}C, and where necessary internal heaters are provided for cold temperatures. Supporting systems include batteries and power-monitoring system.

Routine inspection is through the Tier 1 inspections. Inspection and maintenance procedures follow industry standards. Operational personnel have electrical safety training. Plant Engineering inspects and tests the diesel generators and responds to emergencies.

Normal power from the power distribution system is not required for safety systems; however, the emergency power system is needed for systems that maintain property protection or prevent property loss such as cryogenic controls.

Circuit breakers are typically tested every three years. Presently, the substations are on a 2-year cycle for maintenance and testing. Diesels are test bi-monthly during the warmer months and monthly during the winter.

The diesel/generator tank contains diesel fuel oil and lube oil. Handling of oil is by heavy equipment operators or outside diesel vendor. No oil is discharged intentionally. In order to reduce hazards, bi-monthly inspections of the diesels are performed looking for oil leaks or spills, and industry standards are used for handling oil. Periodic inspection of diesel/generators is performed by Plant Engineering staff.

3.2.9.Design Criteria and As-Built Characteristics of Cooling Water Systems

Figure 3.2.9 depicts the typical two-part water-cooling system used in most CA-Department installations. The Process Water Side pulls heat from the load and transfers it to through the Heat Exchanger to the Cooling Tower Water Side, which dissipates the heat to the air via the cooling tower.

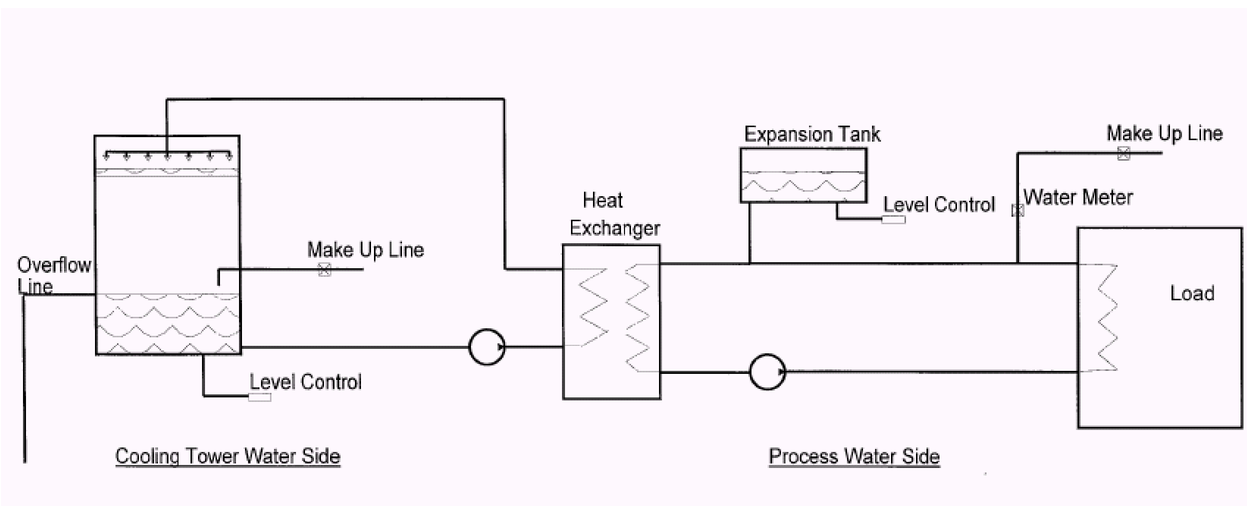
Process Water Side - The heat load is generated from several sources. The source could be from electromagnets, which may be activated by the beams, or from non-activated sources such as power supplies, electronics racks or power buss cooling. This system is completely closed loop. The water level in the expansion tank is continuously monitored using a programmable logic controller (PLC) system that measures the tank's water level, and opens and closes the valve in the Makeup Water Line at specified levels. In addition, the PLC activates alarm signals for the system operator to perform checks to determine the severity and source of any water loss. The system will automatically shut off upon activation of the second-level low-water alarm as well as other system safety parameters.

Cooling Tower Side - This system can be either a closed or an open loop tower-system but both types of tower systems would have basins that are open to air. Most basins have water that is chemically treated with biocides and rust inhibiters but some have ozone treated water systems and a few systems have no treatment at all. In all cooling tower installations, blow-down lines go either to the sanitary system or to storm drains that lead to recharge basins through water monitoring stations.

System Design Specifications - Design guidance for the water piping systems is obtained from the following standards organizations: ASTM, ANSI, ASME and MSS. Suffolk County Article 12 is also applied to all water systems that contain hazardous materials. Radioactivity is defined as a hazardous material for the purposes of Suffolk County Article 12 if the radioactivity level is above the Drinking Water Standard. Typical Article 12 requirements include:

- plans and specifications reviewed and approved by Suffolk County
- impervious secondary containment
- high level alarms to prevent overfilling
- regular documented inspections

Figure 3.2.9 Typical Two-Part Cooling-Water System



Process water has the potential to become activated. Several dedicated process-water cooling systems are distributed throughout the magnet enclosures, supplying cooling water to magnets, targets and RF cavities. Additionally, process-water systems are routed through the enclosures to cool external devices. For example, chilled water is distributed through the AGS ring to the fan houses, where it is used for the ring air-conditioning system. Before disposal, process-water is sampled for radioactivity and metals even if the water is not expected to be radioactive or hazardous. Water samples are obtained using “Chain-Of-Custody” formality and are labeled to identify date, building number and system name. If an effluent is intended, either by collecting spilled water in a sump or by draining down a system, then the sample results are used to determine if the effluent may be low-level liquid radioactive waste.

Process water in about one-third of C-A Department’s cooling systems may contain 12.3-year half-life tritium and trace amounts of other shorter-lived radioactivity; e.g., 53-day Be-7 or 14.9-hour Na-24. With the exception of Building 912 experimental-area cooling towers, process-water systems are closed and are sampled before any planned release. Process water is normally polished by ion exchange and is not changed-out very often, if at all. Ions are removed from process-cooling water because ions allow electric fields to be created around brass connections, which in turn cause the brass to be dissolved away. Major changes to process-water systems may occur every decade or so, and, in recent years, process water has been held and returned to the system after the work is done.

Leaks from primary-water systems are collected by a network of floor drains. Process water entering the floor-drain system is conducted to the sanitary sewer system directly or is collected in sumps. Sumps are alarmed using level indicators. The water is transferred to portable storage tankers and analyzed. In areas such as the Booster and the experimental area in Building 912, water leaks are conducted directly to the sanitary system. At the BNL sanitary wastewater treatment facility, ponds can hold the water if necessary. However, the total tritium in all C-A Department water systems is less than 50 mCi, and is not likely to cause measurable activity concentrations at the sanitary system outfall should activated water make its way to the floor drains. To put this amount of radioactivity in perspective, a single biomedical study at a university may involve 50 mCi of tritium.

The secondary side of closed-cooling systems is well water and cooling tower water, with the addition of treatment chemicals or treatment with ozone. Under normal conditions, the secondary water does not contain tritium. The C-A Department staff relies on a sub-contractor, to manage the chemicals used in cooling waters. The Department monitors all of the automatic systems used to add rust inhibitor and biocide, and they do the weekly analysis of chemical concentrations. C-A Department staff manages systems that use ozone, which results in no chemical additives. Secondary cooling waters are released to recharge basins on the BNL site. These recharge basins are monitored by the BNL Environmental and Waste Management Services Division to ensure that release of water treated with chemicals is within the limits of SPEDS permits.

As indicated previously, most of the process-cooling water systems are closed. There is no exchange other than heat between the primary cooling water and well water and no emissions to air. However, four cooling towers cool the process water from magnets in experimental areas in Building 912. Since these towers are blown-down continuously to maintain a constant temperature range in the magnets, tritium does not build up in the water. However, a small percentage of the dissolved short-lived radioactive gases such as 1.2 minute O-14 and 2.1 minute O-15 are emitted from the towers. Studies of radiation levels associated with emissions to air from the open cooling towers were performed in 1995. These studies showed that emissions from the towers are far below the threshold for continuous airborne radioactivity monitoring required by 40 CFR 61, Subpart H. Periodic sampling is conducted to confirm previous results, as per Subpart H.

3.2.10.Design Criteria and As-Built Characteristics of RF Systems

Particle accelerators may generate pulse powers of many megawatts and generate RF fields. In normal use, RF hazards to staff are negligible compared to those from scattered ionizing radiation. However, during maintenance work close to the magnetron or wave-guide, staff may be exposed to RF fields. Design criteria for RF systems are found in BNL Environment, Safety and Health Standard “RF and microwaves” 2.3.2. Design criteria at C-AD include:

- providing shielding and other control measures to minimize radiation leakage
- guarding exposed dummy loads to prevent burns
- providing adequately sized electrical ground connections to dissipate energy
- eliminating sharp edges or points on equipment to avoid corona discharge
- where possible, provide bypass capacitors on control power and instrument leads that enter the RF compartment to control leakage without interfering with proper operation

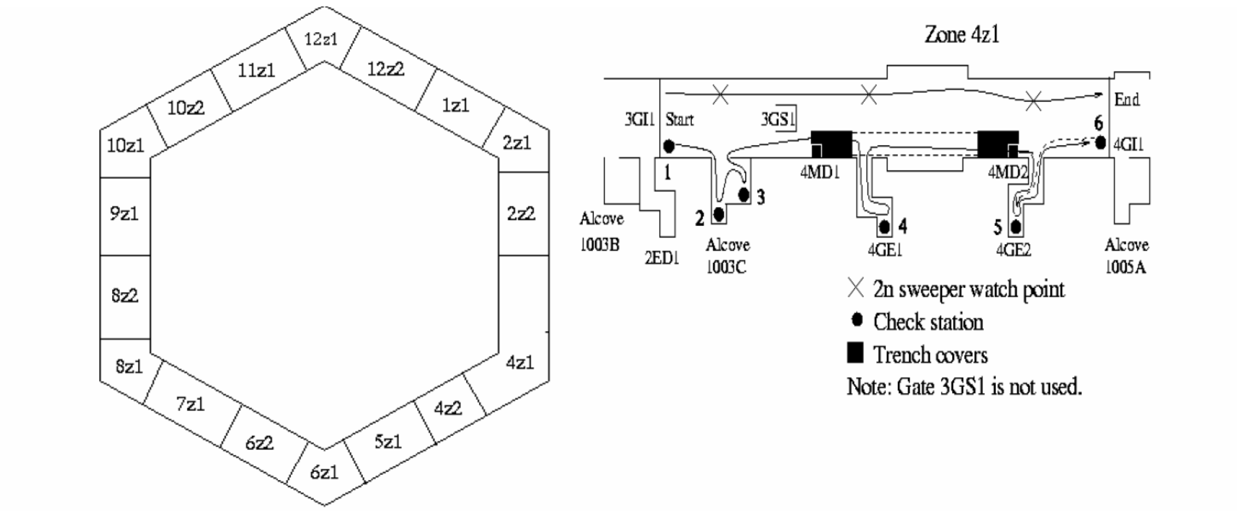
Staff may also be exposed to x-rays from high-power RF equipment, klystrons and accelerating cavities. This is the reason for restricting access to areas where high-powered RF equipment is used.

For example, The RHIC RF accelerating system is located in Buildings 1004, 1004A and the 4 o’clock sector (4z1) of the RHIC tunnel section. There are four 28-MHz accelerating cavities and ten 197-MHz storage cavities. The cavities are an x-ray hazard that has been estimated to be 100 rad/hr maximum for each accelerating cavity and 200 rad/hr maximum for each storage cavity. The absorbed dose-rate estimate is based upon test stand measurements that were extrapolated to a distance of one foot from the cavities using the inverse square law. The measurements were made under high-field emission conditions. The cavities are located the RHIC tunnel.

The 197 MHz cavity measurements were made in the labyrinth from 1004A into the tunnel. In their operating position, the 197 MHz cavities are furthest from the routinely occupied areas and there is an additional leg to the labyrinth thereby significantly reducing the transmission from the tunnel to occupied areas.

In order to allow the cavities to be powered, the 4z1 zone in the RHIC tunnel must be cleared of personnel, and this clearing process is termed a “sweep.” A trained two-person team must perform the sweep. The RHIC Zone 4z1 RF Sweep Checklist (See C-A OPM Chapter 4) is used by the team to document the sweep. The sweep team carries flashlights, chains and approved padlocks for the 4MD1 and 4MD2 trench gates (see Figure 3.2.10). They also carry padlocks for exhaust fan access-doors and walkie-talkies. The sweep team clears the area and uses the appropriate sweep reset-keys to reset the area to allow power to the cavities. Prior to the sweep, the team must assure RF critical devices are safely off.

Figure 3.2.10 Sweep Routine for Enclosure to Powered RF Cavities at RHIC



3.2.11.Design Criteria and As-Built Characteristics of Vacuum Systems

Typical beam vacuum systems at C-A consist of sections of vacuum chambers isolated from the adjacent sections with electro-pneumatic gate valves. Appendages to the vacuum chambers are vacuum pumps and vacuum gauges, which are remotely operated and monitored. The operation of vacuum systems is to provide a friendly environment for the circulating beam and is typically passive such that the failure of vacuum systems will abort the beam and will not cause damage to the other accelerator components and the environment.

All the vacuum chambers are made of stainless steel, Inconel or aluminum for their good mechanical and vacuum properties and radiation resistance. The vacuum chambers are designed and fabricated to meet the accelerator physics and vacuum requirements, and are reviewed by internal and external experts in the field. Design guidance for the vacuum chambers is obtained from the following standard organization: ASTM, ANSI, AVS and ASME. Except the residual radiation on the vacuum chamber walls, there is no inherited hazard in handling the vacuum chambers. C-A Department work planning and procedures are used for removal and installation of the vacuum chambers. A few vacuum chambers and windows are made of beryllium because of its transparency to energetic particles, and the vacuum pipes are handled according to C-A Department procedures for handling beryllium.

There are two types of vacuum pumps, the roughing pumps and the high vacuum pumps. The roughing pumps consist of a turbomolecular pump backed by a mechanical pump and are used during the initial pump down of the vacuum sections. There is little environment and personal hazard in the operation of the roughing pumps. Typical high vacuum pumps at C-A Department are sputter ion pumps powered remotely with 200 mA, 5 kV ion pump controllers. The ion pump controllers are energized continuously during shutdowns. C-A Department LOTO and work planning procedures are used to secure the ion pump controllers when work is performed at or around the vacuum sections.

All the vacuum pump controllers and gate valves are protected through both hardware and software interlocks using standard C-A Department Control System controllers or commercial programmable logic controllers. The controllers generate the appropriate warnings, alarms and valve closure commands, and abort the beam whenever vacuum fault condition occurs. There is no inherent hazard in the operation of these controllers.

Several beam pipe systems, such as Booster and RHIC rings, require bake out at elevated temperatures, typically 250 ^{o}C, in order to outgas the beam pipe for operation at greater vacuum. The main hazards during bake out periods are the use of high voltage and the potential for burns and fire. NEC and NFPA codes are followed. Trained personnel used C-A Department procedures and instructions include local posting and sending a notification to the Fire Captain. The notification describes the location and length of the bake out period. Bake out periods may last for several weeks. Beam pipe bake outs occur infrequently, and usually occur only at the startup of a new or significantly modified system.

3.2.12.Design Criteria and As-Built Characteristics of Radioactive Materials Bldg.

This a single story 22,500 square foot rigid frame structure to house radioactive concrete shielding block, tritiated water storage tanker trailers, and tritiated water drum and resin storage. The structure has a secondary containment foundation system. In addition to following the requirements in Suffolk County Article 12 for the water storage areas, AISC, AWS, RCRBSJ, ASTM, SSPC, ANSI and NFPA standards and codes were followed for building construction.

Ordinary and heavy concrete shielding blocks ranging in length from 1 to 30 feet and from 0.5 to 10 feet in the other dimensions are stored in this facility. Transfer is affected by crane. Transport is accomplished by vehicles of various sizes as required. Although activated, these shielding blocks represent significant investment and resources for the C-A Department.

The C-A Department operates many cooling water systems in support of the operations of the various accelerators, collider and experiments within the C-A facility. Some of this cooling water removes heat from components that are subject to interaction with primary or secondary beams. Because of this, some of the cooling water becomes activated with short-lived and long-lived radionuclides.

In order to reduce liquid waste volumes, activated water is stored in tanker trailers that are part of the cooling water process system for potential reuse. For example, if a component must be replaced in a cooling water system or a cooling water system design modified, the system water is drained into the tanker for storage during repairs or modifications and transferred back into the system when repairs/modifications are completed. This recycling is a pollution-prevention waste-minimization activity, a desired activity of the BNL Environmental Management System. Water from any of the many cooling waters systems may be co-mingled in these tankers. This water is maintained for reuse and is not routinely discarded.

It is noted that all C-A Department water processes, including tanker use, are reviewed and documented under the C-A Department's Environmental Management System. Each process has an Environmental Management Program, an Environmental Training Program, Procedures and Operational Controls. Each year, independent auditors examine C-A Department's Environmental Management System in order to maintain ISO14001 registration.

The Radioactive Materials Storage Building meets all Article 12 requirements and has a roof so that rainwater will be kept out of the tanker's secondary containment system. The floors are impermeable to water and are sloped toward a trench that can hold 110% of the volume of any tanker. The facility is equipped with communications for alarms and a steam heater to provide freeze protection for the tankers.

3.3. Design Features and Processes that Minimize Hazards

The design features and processes that minimize the presence of hazardous environments and ensure radiation exposures are kept as low as reasonably achievable during operation, maintenance and facility modification are summarized as follows:

Radiological Hazards

- dual, fail-safe interlocks are used on gate entrances (if >50 rem/hr)
- interlocked access-key-trees are used to capture gate access keys
- bio-identification systems are used to release an access key to a trained individual
- crash cords and/or crash buttons are mounted inside accelerators, intersecting regions, target caves and beam lines
- interlocking area radiation monitors with pre-set trip levels are located throughout the complex
- audible and visual warnings are issued before re-enabling an accelerator, beam line, intersecting regions, or fixed target area to receive beam
- accelerators, intersecting regions, beam lines and target areas are fully enclosed to prevent access during operations
- fencing and/or barriers are used to limit access to radiological areas
- shielding is thick enough to prevent exposure to primary beam
- multi-leg penetrations and labyrinths are used to minimize routine radiation levels
- re-entrant cavities are used to minimize exposure to residual radiation from beam dumps

Oxygen Deficiency Hazards

- warning signs posted at entrances to areas classified as ODH
- ODH training required for persons working in ODH Class 0 or greater
- medical approval required for ODH-qualified personnel working in ODH Class 1 or greater
- personal oxygen monitor for staff working ODH Class 1 or greater
- self-rescue supplied atmosphere respirator for staff working ODH Class 1 or greater
- automatic ventilation fans turn on if oxygen deficiency occurs in the RHIC Ring
- audible and visual warnings if sensors record O_2 levels below 18%

Electrical Hazards

- there are no exposed conductors; all magnet buss work has covers
- the National Electric Code is enforced for all facility electrical distribution systems
- in-house-built electrical devices are reviewed for compliance with the National Electric Code by the Chief Electrical Engineer according to C-A OPM procedure
- fusing and other protective circuitry are used in experimental equipment in accord with C-A OPM procedures
- accountable key systems, such as captive key or Kirk Key where a key must be physically removed from one position and inserted in another lock to provide access, are used in accord with SBMS/BNL ESH Standard requirements
- there are emergency-off controls for power

Life Safety and Fire Protection

- manual fire alarm stations are located adjacent to exterior exit doors
- fire detection, in the form of smoke detection, is located throughout the facilities

- fire alarms are provided throughout the facilities
- fire sprinkler protection is located in areas of high value
- fire department hose standpipes are located at the entrances to facilities.
- wet pipe sprinkler systems are hydraulically designed for 0.15 gallons per minute per square foot over 2500 square feet of the most remote area
- wet pipe sprinkler systems are hydraulically designed for 250 gallons per minute for hose streams
- exits meet the requirements of the Life Safety Code
- the use of flammable liquids is minimal and any use of flammable liquids follows SBMS requirements
- any use of flammable gases follows SBMS requirements
- emergency lighting is provided throughout the complex
- fire extinguishers are provided throughout the complex with 75 feet as the maximum travel distance to an extinguisher

Hydrogen Targets

- target windows are tested against puncture
- target vacuum sensor and hydrogen detectors are interlocked to the power supply to nearby experimental detectors
- upstream and downstream experimental detectors and chambers are protected with fire wire and smoke detectors
- fire wire and smoke detectors interlock the electric power to the experiment and cause alarms to go off alerting both MCR operators and the target watch

- before a target installation, the environment around the target is reviewed for potential ignition sources (pre-amps, cabling, power-supplies, gas flow systems, detectors and detector chambers are examined)
- written procedures are required to operate experimental chambers and gas systems around the target
- routine portable sampling for hydrogen or any other flammable gas in use near the target is required before startup and following shutdown
- voltages on experimental equipment are required to be on before hydrogen or deuterium is introduced to the target
- alarm responses are written into formal procedures and the target watch is trained, again before the introduction of hydrogen or deuterium to a target
- work on or around the target is forbidden unless the hydrogen or deuterium is removed
- fire wire and smoke detectors are required to be operational at all times or the hydrogen is vented off
- failed smoke detectors are not bypassed while the target is in operation

3.4.Design Features and Processes that Prevent Pollution

To provide excellent science and advanced technology in a safe and environmentally responsible manner the C-A Department reviews the aspects of its operations in an effort to identify pollution prevention opportunities and accomplish waste minimization. This process began in 1988 with the development of formal environmental design guides and a design review process at C-A Department. More recently, this program, now called Environmental Management System (EMS) has met the requirements of ISO 14001. Based on the aspect identification and analysis process in the SBMS, the following environmental aspects are significant to C-A Department operations:

- regulated industrial waste
- hazardous waste
- radioactive waste
- mixed waste
- atmospheric discharge
- liquid effluents
- storage/use of chemicals or radioactive material
- soil activation
- PCBs
- water consumption
- power consumption
- environmental noise

BNL's Facility Review Project and the Process Evaluations, which were initially conducted in 1999, served as the technical baseline through which significant aspects at C-A Department were systematically identified. The C-A Department reviews Process Evaluations annually or as required if a process is changed, and updates the EMS documentation when appropriate.

The C-A Department assures that environmental goals in the BSA contract are achieved and that C-A Department activities are in accord with regulatory requirements. Annually, the contract-derived environmental objectives and targets are documented in the C-A Department EMS for each process and the responsibility for achieving specific environmental objectives is assigned to staff. Meeting regulatory requirements is assured by involving one of BNL's Environmental Compliance Representatives (ECR) in the evaluation of work tasks and in the review of experiments. C-A Department environmental objectives and targets also incorporate objectives and targets recommended through senior management reviews of the C-A Department EMS. Due to the nature and scope of C-A Department operations, there are two ongoing environmental objectives: prevention of groundwater contamination from activated soils, and reduction of legacy materials produced by past experiments.

On a day-to-day basis, the C-A EMS is executed through safety reviews and work planning. The ECR serves on both the Experimental Safety Review Committee (ESRC) and the Accelerator Systems Safety Review Committee (ASSRC). It is the responsibility of the ECR to review activities for implementation of environmental controls and to add or revise C-A environmental aspects as required. Identified EMS action items are incorporated into the work planning process, or are closed out in the experiment or accelerator-modification review and approval process.

Formal training and qualification programs for the operation of equipment, processes and procedures that could have a significant impact on the environment are documented. At C-A Department, job-specific training is developed for environmental processes that involve significant aspects. Employees that interact in these processes are required to go through training.

Internal communication of significant aspects and EMS strategies occurs through a schedule of weekly planning meetings. During these structured meetings, involving appropriate personnel, work is planned and evaluated, concerns of safety, equipment, hazards and environment are addressed and resources are allocated. External communications includes correspondence with regulators, DOE-BHSO, suppliers, customers, civic groups, elected officials, public and the media. External communications regarding EMS is also posted on the web.

The C-A Department document control system, which includes EMS documents, is developed in compliance with Laboratory requirements is SBMS. In addition, C-A Department records are managed through implementation of SBMS requirements. The C-A Department has identified all significant operational, environmental, safety, health, training and quality records.

The C-A Department has an established emergency preparedness and response plan. This plan is detailed in the OPM Chapter 3 and is intended to provide general guidance for use in responding to most incidents, which may arise at C-A Department facilities. In addition to the plan, specific procedures for reporting and mitigating environmental impacts are in the OPM Chapter 10.

The C-A Department documents its environmental nonconformance, corrective, and preventive actions primarily through ORPS. All non-ORPS events are documented using the SBMS Subject Areas on “Critiques” or “Nonconformance & Corrective and Preventive Action.”

Assessments and audits are used as the basis for examining, identifying and correcting weaknesses within the C-A Department EMS program to facilitate improved performance and compliance. EMS audits are scheduled, performed and tracked through the Assessments and Tracking System (ATS) database. C-A Department EMS audits are conducted, at a minimum, annually.

As a routine part of operations, C-A Department managers conduct reviews of EMS. These meetings are held both weekly and monthly. Annually, the C-A Department EMS is reviewed with BNL senior management. The senior management review is accomplished in accordance with the provisions of the SBMS.

Because of EMS and prior environmental protection programs at C-A Department, many design features and processes that ensure pollution prevention were developed and implemented. They are summarized as follows:

Liquid Effluents

- sumps and sump alarms are located appropriately to capture cooling water should it leak
- all drain piping in facilities is either connected to sumps or connected to the BNL Sanitary Sewage System
- all cooling water systems have water make-up alarms
- make-up water to activated cooling systems is tracked by computer and records are retained
- outdoor tritiated water piping or cooling systems have been eliminated with few exceptions; the exceptions have secondary containment
- isolated closed cooling-water systems are used to reduce the total volume of tritiated water
- connections to the domestic water supply are equipped with back-flow preventers

- secondary containment is used in compliance with Suffolk County Article 12

Airborne Effluents

- hoods and individual laboratory ventilation with filters are used for laboratory work with radioactive and hazardous materials
- air and short-lived (minutes) airborne radioactivity are re-circulated in accelerators, beam lines and most target areas to allow for radioactive decay of airborne radioactivity *in situ*
- fixed target areas for heavy-ion experiments are exhausted to minimize exposure to experimenters who must make frequent entries; however, airborne emissions from these low-intensity target-areas results in less than 0.1 mrem per year to the maximum exposed member of the public
- short-lived airborne radioactivity may be emitted from cooling-water towers near Building 912 fixed-target experimental areas; however, airborne emissions from C-A Department cooling-water towers results in less than 0.1 mrem per year to the maximum exposed member of the public
- tritium air emissions result from recycling process-water held in water tankers that are heated for freeze protection in the cold weather; however, airborne emissions from C-A Department water tankers results in less than 0.1 mrem per year to the maximum exposed member of the public

Activated Soil Areas

- activated soil and areas where soil activation is anticipated to cause the groundwater to receive leachate that exceeds 5% of the DWS are capped with impermeable barriers

- the maximum allowable rainwater infiltration rate through the cap is designed to be less than 0.3% of the infiltration rate for natural, uncapped soils at BNL
- the long-term average infiltration rate through the cap is designed to be less than 0.2% of the natural groundwater recharge rate at BNL
- environmental issues are reviewed by the RSC and ALARA committees and they review soil activation, air activation, ground water activation and erosion of soil shielding
- RSC and ALARA committees determine position of protective caps that prevent rainwater leaching of the activated soil, and they review groundwater activation and airborne activity estimates

Steel Storage Yard

- quarterly inspections of areas are performed as part of the Tier I process to assure that materials are visibly clean, and intact with no evidence of corrosion or flaking
- steel handling equipment (forklifts/cranes) is routinely checked for evidence of fluid leakage

Shielding Storage Yard

- quarterly inspections of areas are performed as part of the Tier I process to assure that materials are visibly clean, and intact with no evidence of corrosion or flaking
- shield handling equipment (forklifts/cranes) is routinely checked for evidence of fluid leakage

Radioactive Materials Storage Building

- secondary containment is used in compliance with Suffolk County Article 12
- the portable storage container area is designed in compliance with Suffolk County Article 12
- all drain piping is either connected to sumps or connected to the BNL Sanitary Sewage System
- indoor storage by design keeps outside elements from degrading shielding blocks and additional material otherwise stored outside

Storm Drains

- all drainage has been redirected either to a recharge basin or to the Sewage Treatment Plant
- a listing of liquid effluents and discharge points by building was prepared as part of the Facility Use Agreement (FUA)
- recharge basins are sampled on a scheduled basis to assure that all releases are within the State Pollutant Discharge Elimination System (SPDES) Permit
- excursions beyond any allowable limits are reported to the appropriate regulatory agencies and immediate remedial action is taken

Sanitary Sewer System

- the Sanitary sewer system is continuously monitored to verify compliance with the State Pollutant Discharge Elimination System (SPDES) Permit levels
- excursions beyond limits are investigated and corrective action is taken
- in the event of an accident or a potentially unwanted discharge, the Sewage Treatment Plant has the capability to divert the discharge into large holding ponds and take appropriate actions to remediate the “held” discharge

Tanks That Contain Petroleum or Toxic or Hazardous Materials

- labels are conspicuously displayed on the tank
- associated piping is labeled at the point of building penetration and at points of filling or drawing
- records of product delivery and consumption are maintained for five years
- daily inspections are performed on tanks, piping and secondary containment systems for evidence of spillage or leaks
- leaks are investigated immediately and corrective actions performed to repair the system
- monthly checks are performed on leak detection and hi-level monitoring systems, and inspection of the condition of the tank system and secondary containment
- records of checks are maintained for five years
- inoperative systems or system deficiencies are repaired immediately and noted in the record
- cathodic protection systems are tested annually
- when required, routine tightness tests of piping are performed and all tightness testing is performed in the presence of Environmental Compliance and Suffolk County personnel

Water Consumption

- water consumption is minimized, when feasible, through the re-use of system water when a system is drained
- C-A has minimized its use of once through cooling water in its systems
- the Main Magnet water system's heat exchanger is equipped with a regulator and valve to allow on-demand cooling and minimize water consumption

Power Consumption

- procedures in the C-A OPM assure that power consumption is monitored, controlled and minimized
- monthly electrical power limits are set for the C-A Department
- daily power usage is monitored by the C-A Department
- a protocol is in place to shed unnecessary electric loads when an experiment is ended, and when the power is no longer needed for safety, equipment testing or maintenance
- electrical power usage is reviewed annually for implementation of new engineering controls or standard operating procedures

Radioactive Materials Storage Areas

- all liquid wastes are kept in secondary containment
- all bins and bags are kept closed or sealed
- materials are segregated and labeled to eliminate improper disposal
- large storage areas are inventoried and inspected at a minimum of yearly; most areas more checked more frequently via the C-A Department Tier I process and the BNL FS Group

- wherever reasonably achievable, radioactive materials are stored indoors to avoid interaction with the environment

Chemical Storage Areas

- all chemicals are labeled to avoid improper uses and accidents that would affect the environment
- chemicals are stored in fireproof cabinets and in secondary containment
- spent chemicals and fluids are placed in satellite accumulation areas in sealed labeled containers for appropriate disposal, which is in accordance with the SBMS
- Tier I inspections include a review of chemical storage in each area
- deficiencies such as insufficient labeling and inappropriate storage are corrected during inspections by the C-A Environmental Coordinator, and/or C-A Environmental Compliance Representative

Hazardous, Radioactive and Mixed Waste

- the most significant pollution prevention activity performed by the C-A Department is in the recycling and reuse of radioactive beam-line components
- magnets, bus work, cable trays, steel, cable, vacuum pipe, beam instrumentation and shielding blocks are reused
- any material not classed as hazardous, radioactive or mixed is disposed of through area recycling companies
- all liquid waste is kept in secondary containment
- all bins and bags kept closed or sealed
- materials are segregated and labeled to help eliminate improper disposal

- to avoid unnecessary shipments of waste, where possible, oils are recycled and burned through the Central Steam Facility for power generation
- an evaluation is performed to see if any material can be reused or recycled before putting it into a waste stream

PCBs

- PCB inventory is replaced with non-PCB items where appropriate and applicable
- PCB's and equipment with PCB's are checked in routine intervals for leakage and labeling
- equipment with PCB's and spare PCB's are in secondary containment
- ADS funds and Pollution Prevention funds requested to replace PCBs

Noise Areas

- the C-A Work Planning Manager performs noise assessments where required and stipulates the appropriate hearing protection for workers within the area
- laboratory management has been sensitive the community's concerns over noise created by RHIC compressors
- the C-A Department has reviewed designs of new facilities and modifications to older facilities to minimize and redirect noise whenever compressor building doors are open
- C-A has put a policy in place to have the doors open only during reasonable daylight hours of operation

3.5.C-A Department's Organization

The C-A Department is administered and organized to assure safe operation in accomplishing its mission. Its mission is to:

- excel in environmental responsibility and safety in all department operations
- develop, improve and operate the suite of proton/heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL
- support the experimental program including design, construction and operation of the beam transports to the experiments plus partial support of detector and research needs of the experiments
- design and construct new accelerator facilities in support of the BNL and national missions.

In meeting its mission, the C-A Department is under a formal Conduct of Operations Agreement with the Department of Energy.[16] The documentation used to comply with this agreement is the C-A Department Operations Procedure Manual, Collider-Accelerator OPM,[17] which specifies key procedures, chain of command, authorized personnel and other operational aspects. The process used to assure that personnel are qualified in safe operations is an extensive training program, including formal examinations to certify operational qualifications where appropriate.

The C-A Department organization[18] is comprised of four Divisions, the Accelerator Division, the Experimental Support and Facilities (ES&F) Division, the Controls Division and the Environmental, Safety, Health and Quality (ESHQ) Division. It is the responsibility of the

[16] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm Conduct of Operations Agreement
[17] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm Operations Procedure Manual
[18] http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf C-A Organization Chart

Accelerator Division to bring two motor generators, the Siemens motor generator or Westinghouse motor generator, and seven accelerators, two Tandems at TVDG, Linac, Booster, AGS and two rings at RHIC on line and to integrate the operation of these machines into that of the complete facility. The beams from the operation of the seven accelerators must be transported by operations through transfer lines: Tandem to Booster (TtB), Linac to Booster (LtB), Booster to AGS (BtA) and AGS to RHIC (AtR), and to experimental areas. Beams must also be transported to experimental areas: TVDG Target Rooms, NASA Space Radiation Laboratory Target Room, Building 912 experimental areas, Building 919 experimental area and RHIC intersecting regions. It is the responsibility of the ES&F Division to plan, design, build and maintain the primary and secondary experimental beam lines and provide technical support for instrumentation for experiments or accelerators. It is the responsibility of the Controls Division to provide software development and hardware support for the accelerators. It is the responsibility of the ESHQ Division to provide environmental protection, safety and health related services to the staff and experimenters. The ESHQ Division provides technical work products, training services, referrals to outside professionals, documentation services, conventional and radiological safety services, environmental management, waste management and internal assessment resources to help resolve problems and meet requirements.

3.5.1. Operations Organization Introduction

The RHIC, AGS, Booster, Linac and Tandem Van de Graaff accelerators operate through the C-A Department Main Control Room in Building 911. The C-A Department's organization for operations is pictured in Figure 3.5.1. Responsibility for the safe and reliable operation of the C-A Department complex resides with the on-duty Operations Coordinator. The Operations Coordinator is the shift supervisor for the operating personnel and the focus for all operations related questions. Aside from accelerators, the Collider-Accelerator complex is made up of a number of facilities that include the motor generators, water systems, RF acceleration system, vacuum system equipment, injection equipment, extraction equipment, cryogenic equipment, transfer lines, beam lines, target halls and the experimental areas. Personnel that are responsible for the day-to-day operations of these facilities are members of the Accelerator Division, the ES&F Division, the ESHQ Division and the Controls Division. Additional personnel who support the operations are members of BNL's Radiological Controls Division, Environmental and Waste Management Services Division and Plant Engineering Division.

Depending on operations, personnel available to the Operations Coordinator during operations may include:

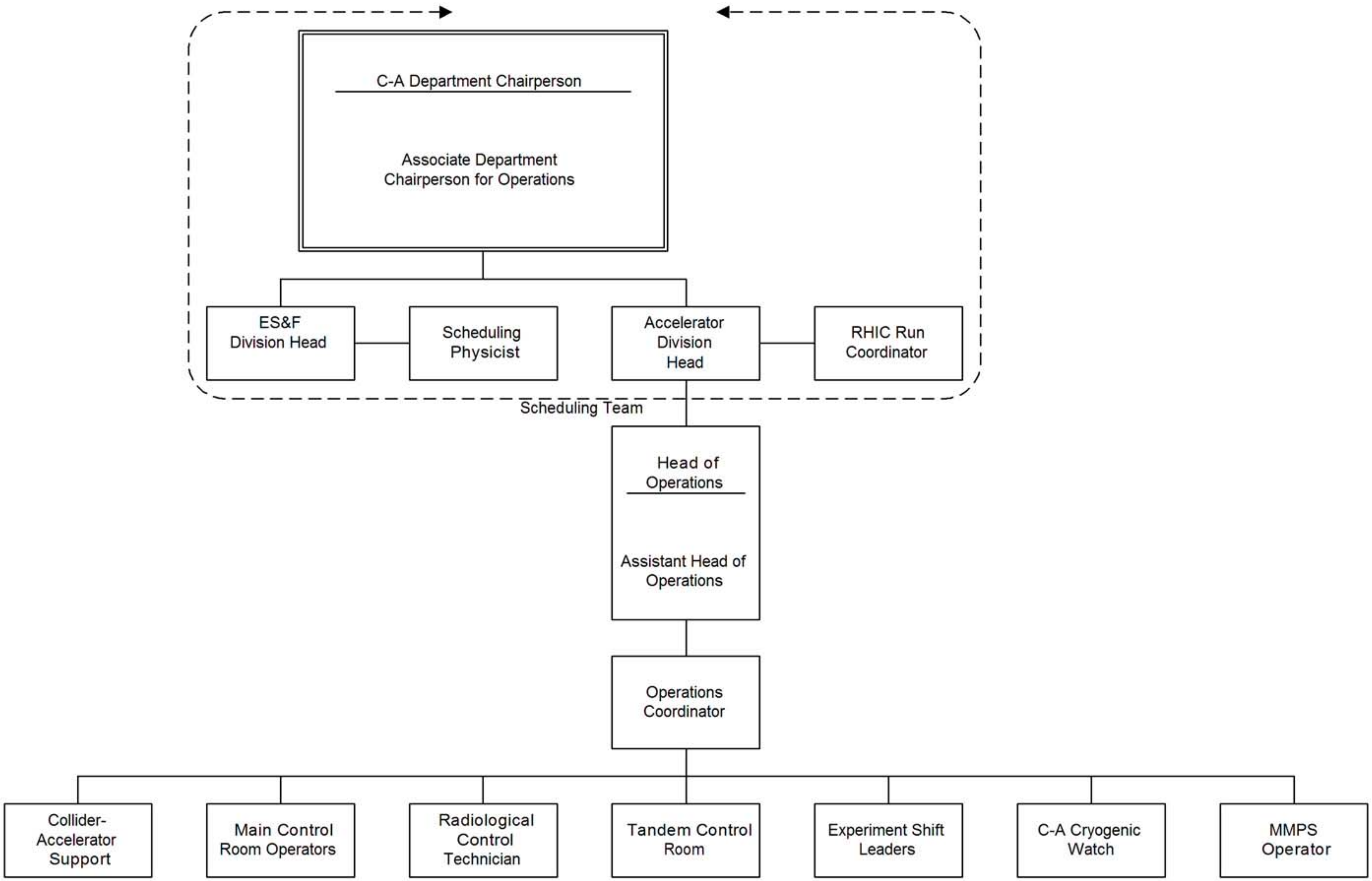
- the Main Control Room Operators
- the Collider-Accelerator Support who are responsible for accelerator and experimental area systems and beam line components
- TVDG Control Room Operators
- Power Room Operator who is responsible for the control of the AGS Main Magnet Power Supply
- Cryogenic Target Watch who are responsible for the operation of the liquid cryogenic targets, if any

- Cryogenic Control Room Supervisor and Operators who are responsible to operate the refrigeration systems for cooling cryogenic magnets
- Radiological Control Technician
- Experiment Shift Leaders at the collider experimental areas
- lead experimenter at the fixed-target experimental areas

Additional personnel available to the Operations Coordinator include the accelerator physicists and equipment systems specialists. Accelerator physicists are scientific personnel trained to be familiar with the theory and/or practice of the physical processes underlying the operation and performance of the Linac, TVDG, Booster, AGS, RHIC and the accelerator systems in the experimental areas. Systems specialists repair equipment necessary for operations or provide trouble-shooting expertise when machine physics or equipment problems arise. Occasionally, it is necessary that parts of the accelerator complex be operated by accelerator physicists or systems specialists. The rules governing access to accelerator controls, by such individuals, are found in the Collider-Accelerator OPM. In order to be allowed access to accelerator controls, accelerator physicists and systems specialists must:

- recognize the role of the on-duty Operations Coordinator as the decision-maker regarding the safe and reliable operation of Collider-Accelerator facilities
- follow the orders of the Operations Coordinator, or his designate, during an emergency
- not operate any access-control-system consoles unless authorized to do so by the Access Controls Group Leader
- request permission to use the accelerator controls and state the purpose for the use of the controls to the on-duty Operations Coordinator.

Figure 3.5.1 C-AD Operations Organization



3.5.2. Operations Authority

Safe operation and maintenance of the C-A Department's science and technology (S&T) machines, injection systems, and experimental areas are under the supervision of the C-A Department Chair, the Accelerator Division Head, the Experimental Support & Facilities (ES&F) Division Head, the on-duty Operations Coordinator and the supervisory structure. See the Collider-Accelerator Organization Chart.[19]

Only authorized Department personnel operate the S&T machines. Direct daily supervision of shift operations is the responsibility of the on-duty Operations Coordinator. All Operators are authorized to shut down the S&T machines whenever an unsafe condition arises, or whenever they think that continued operation is not clearly safe. They are also authorized to take any other corrective safety- or environmental-protection-action as indicated in the Collider-Accelerator OPM. All scheduled operational-related maintenance is done with the authorization of the appropriate Work Coordinator, with the work-control authorizations prescribed in the Collider-Accelerator OPM and with the knowledge of the on-duty Operations Coordinator.

All operations have the appropriate authorization. Current holders of positions are denoted in the Collider-Accelerator Organization Chart. The following operations authorities are listed in the OPM:

- Department Chair authorization
- Associate Chair authorization
- Assistant Chair authorization
- Division Head authorization

[19] http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf C-A Department Organization Chart

- Group Leader or Supervisor authorization
- authorization to operate systems
- accelerator startup or restart authorization
- work control authorization
- Maintenance Coordinator authorization
- authorization to classify, remove or designate approval for procedures
- Department Chair, Division Head, Group Leader, committee chair and QA authorization of procedures
- committee membership and organization chart authorization
- modification of training authorization
- authorization to approve QA level classifications
- authorization to approve purchase requisitions and intra-laboratory requisitions for ESHQ compliance
- authorization to declare systems as "critical"
- authorization to approve working hot permits and procedures
- authorization to approve lock and tag checklists
- authorization to approve experiments
- authorization to approve new or modified accelerator systems
- authorization to approve new or modified shielding and access control systems

3.5.3. Administration and Organization of ESHQ

The administration of ESHQ at C-A Department is via a hierarchy of documents: BNL Policies, BNL Standards of Performance, R2A2s, BNL Management Systems, BNL Subject Areas, Safety Analysis Document, Accelerator Safety Envelope, C-A Department Conduct of Operations Agreement, C-A Department Facility Use Agreements, and at the working level, department procedures (Operations Procedures Manual).

BNL ESHQ Policies are the highest-level statements of BNL organization's philosophy for conducting business in a safe and environmentally sound manner. The number of policies is small. Policies are intended to form the complete set of foundational philosophies upon which the Laboratory operates.[20]

Standards of Performance are BNL "requirements" underlying Laboratory-wide procedures. Standards of Performance are intended to set performance expectations for BNL systems, managers and staff in accomplishing BNL Policies. By definition, the term "staff" includes all BNL staff and managers. Standards of performance also apply to those guests, visitors and users who have a guest number and have a DOE photo identification badge. Standards of Performance are high-level behaviors by which BNL carries out its policies, and are used to determine whether we are conducting our business and ourselves consistently with our mission, values and aspirations.[21]

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[20] https://sbms.bnl.gov/policies/cl00d011.htm BNL Policies
[21] https://sbms.bnl.gov/perform/gstdd011.htm BNL Standards of Performance

The role, responsibility, accountability and authority statements (R2A2s) establish the expectations and duties of managers and staff for carrying out the work consistent with external and internal requirements.[22]

Management Systems are designed to translate the full set of external requirements into the information staff need to perform their work. Management systems are BNL's highest-level operating and business processes.[23]

Subject Areas are prepared when the requirements, procedures and guidelines apply to a broad group of staff across BNL.[24] If information only applies to a select or small group of staff, alternate methods of communications exist, such as task- or group-specific internal operating procedures. Subject Areas provide Laboratory-wide procedures and guidelines. They are developed to support the implementation of Standards. In some cases, specific program description documents are used as the basis for operations by discrete groups of BNL staff that perform key activities to operate the processes and systems. In the case of the C-A Department, the basis for operations is defined in the Conduct of Operations agreement[25], the Safety Analysis Document and the Accelerator Safety Envelope.

A Facility Use Agreement (FUA) is also established for C-A Department Facilities. The C-A Department Chairman, the Assistant Laboratory Director for Facilities and Operations and the Deputy Director of Operations are the agreement parties for the FUAs. The FUAs clearly documents the respective roles, responsibilities and authorities for the C-A Department Chair and the Assistant Laboratory Director for Facilities and Operations for all aspects of facility operations. The DOE approved safety/authorization basis document for C-A Department accelerator facilities, which is the Accelerator Safety Envelope (ASE), is a referenced attachment

[22] https://sbms.bnl.gov/standard/0x/0x00t011.htm Roles, Responsibilities, Accountabilities and Authorities
[23] https://sbms.bnl.gov/mgtsys/ms00t011.htm Management System Descriptions
[24] https://sbms.bnl.gov/standard/0000t011.htm Subject Areas
[25] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm Conduct of Operations Agreement

to the FUA. Facility Use Agreements (FUAs) define the operating boundaries/requirements including roles and responsibilities for the various C-A facilities.[26]

Internal operating procedures include task- or group-specific procedures that are used to implement management system processes. C-A Department procedures typically affect only C-A Department facilities. The Collider-Accelerator ESHQ Division ensures that Operations Procedures are current and that they are based on the Laboratory-level governing documents[27] and the DOE approved SAD/ASE.

Each individual at the C-A Department is responsible for knowing and observing the rules. If any trained personnel observe any potential hazards, environmental problems or safety problems, then they must stop the work or activity and report it. Supervisors are responsible for all activities conducted within their facilities. C-A Department managers are committed to providing a safe and healthy working environment for all staff; protecting the public and the environment from unacceptable environmental, safety and health risks; operating in a manner that protects the environment by applying pollution prevention techniques to current activities; and remediation of environmental impacts of past operations.

All Collider-Accelerator personnel are knowledgeable in applicable procedures located in the Collider-Accelerator Operations Procedures Manual (OPM). The OPM is designed to be a controlled document and to conform to quality assurance requirements set down in the Collider-Accelerator Quality Assurance Procedures.[28]

The C-A Department ESHQ organizations are indicated in Figure 3.5.3. Several key ESHQ organizations and programs are described as follows:

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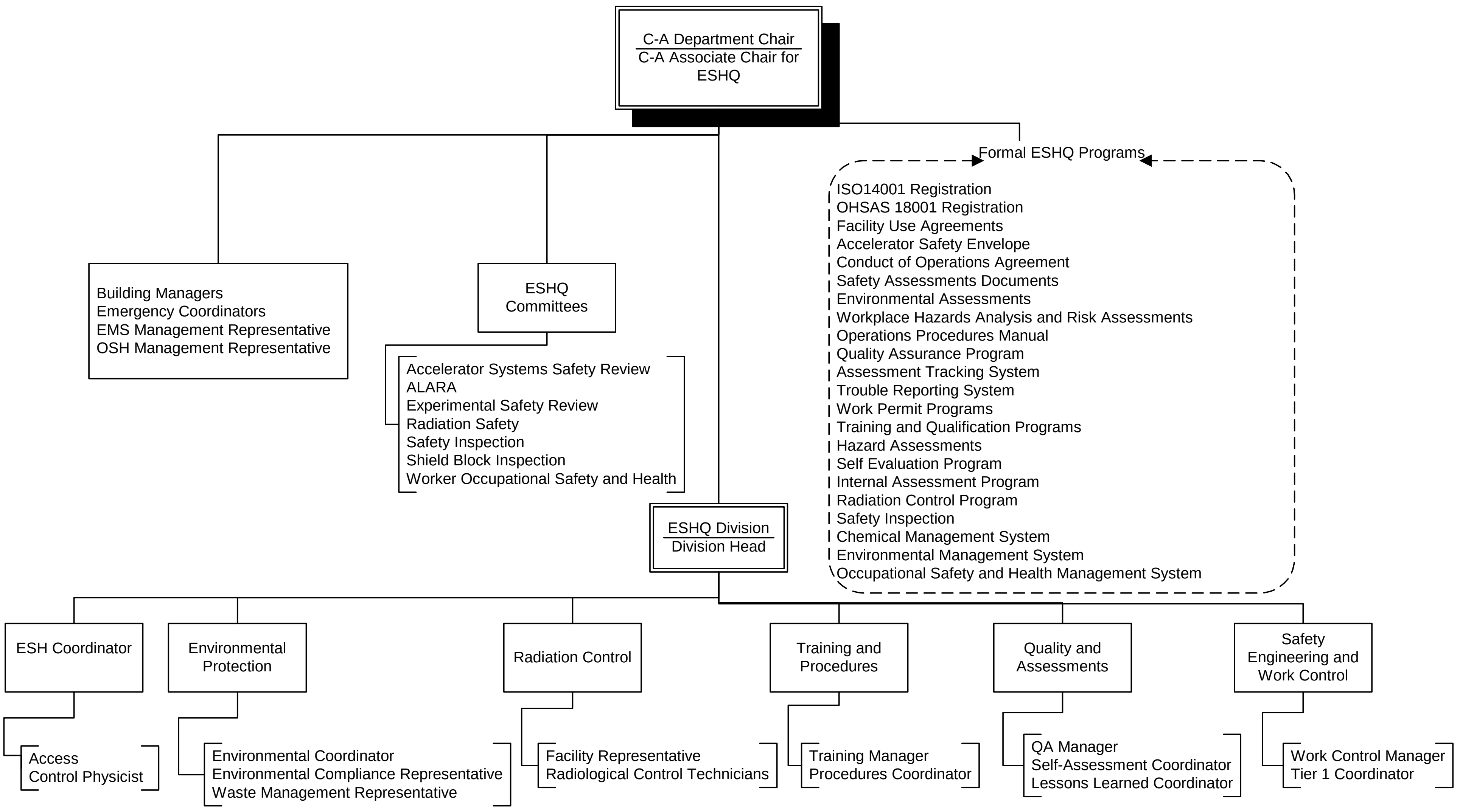
[26] https://sbms.bnl.gov/private/fua/fa00t011.htm Facility Use Agreements
[27] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm C-A Department Procedures
[28] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm C-A Quality Assurance Procedures

The Associate Chair for ESHQ is a member of the C-A Department Chair's Office. The Associate Chair's functions are to implement new or revised environmental, waste, safety, health, training and quality programs, to carry out the leadership role for ESHQ, to inform personnel on the status of ESHQ, to establish communications and to maintain existing ESHQ programs. The overall approach is to integrate ESHQ into all work via formal Collider-Accelerator programs and procedures designed to ensure BNL's management systems are executed. BNL's management systems, which are located in the Standards Based Management System,[29] are in turn designed to ensure that contractual requirements set by DOE are met.

[29] https://sbms.bnl.gov/ch00d011.htm, BNL's Standards Based Management System

Figure 3.5.3 Organization and Formal Programs for ESHQ at C-A Department



For DOE, “safety” encompasses environmental protection, safety and health, including pollution prevention and waste minimization. DOE has identified five Core Functions to manage “safety.” They are:

- define the scope of work
- identify and analyze hazards
- develop and implement hazard controls
- perform work within authorization agreement
- feedback and improvement

DOE has identified seven Guiding Principles for performing the five Core Functions. The first three Principles apply to all Core Functions, the others to specific Functions given in parentheses:

- line managers are clearly responsible for “safety” (all Core Functions)
- clear “safety” roles and responsibilities are defined (all Core Functions)
- competence is commensurate with responsibilities (all Core Functions)
- priorities are balanced (define work)
- “safety” standards and requirements are identified (define work, identify hazards, develop controls)
- hazard controls are tailored to work (develop controls)
- operations authorization has been given (perform work)

The management system that includes the five Core Functions and seven Guiding Principles has been named the Integrated Safety Management (ISM) by DOE. BNL’s management systems to implement ISM are located in the Standards Based Management System (SBMS). SBMS is on-line with links to all referenced documents. The SBMS satisfies the contractual requirement for ISM. SBMS includes the following principal ESH programs and management systems:

- BNL's Integrated Assessment Program
- Laboratory level work-definition documents such as Subject Areas and BNL ESH Standards
- Facility Use Agreements (FUAs)
- Role, Responsibility, Authority and Accountability documents (R2A2s) and performance goals
- Brookhaven Training Management System (BTMS)

At the Department level, SBMS guides planning and control of experiments, and it is used to:

- determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns
- develop an experimental plan and identify controls
- set up an experiment and obtain Experimental Safety Review Committee concurrence
- approve start-up and perform the experiment according to plan
- determine ways to improve next time

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, SBMS guides work planning and control for operations, and it is used to:

- define the scope of work in a Work Permit or establish the applicability
- identify the hazards via the Work Permit process and perform a pre-job walk down
- use the Work Permit processes to establish hazard controls and required training
- provide the pre-job briefing and perform the work according to plan/permit

- use the Work Permit feedback process to identify ways to improve next time

The C-A Department uses safety committees and ESH staff to define the scope of the experiment or work, identify and analyze hazards and develop hazard controls. The ALARA Committee, Experimental Safety Review Committee, Accelerator System Safety Review Committee and Radiation Safety Committee meet requirements established in SBMS. These Committees are composed of members of the C-A Department, other BNL scientific Departments and members of the BNL ESHQ Directorate. These Committees operate under a system of formal procedures contained in the C-A Department OPM.

Self-assessment and self-evaluation are carried out by managers using the Management Review process, by individual Department employees and by C-A Department's Safety Inspection Committee, Shield Block Inspection Committee, Worker Occupational Safety and Health Committee (WOSH) and the Quality Group. Formal procedures for conducting self-assessments and self-evaluations are listed in the C-A Department OPM. Formal tracking is via the Assessment Tracking System (ATS).[30]

Management Review is a process whereby senior managers review C-AD targets and objectives to ensure they relate to critical outcomes and objectives in the BNL contract. They also examine the formal C-AD programs that affect occupational safety and health, environmental protection and self-assessment. They review compliance audit results, performance versus contract measures, other external and internal assessments of performance, decisions from previous Management Reviews, injury/illness and environmental performance, stakeholder concerns, related facility improvements, injury/illness and pollution prevention initiatives, and related financial investments. At the end of the process, senior management

[30] http://ats.bnl.gov/ Assessment Tracking System

provides a record of decisions to drive the next cycle of continuous improvement in occupational safety and health and environmental protection.

The WOSH Committee ensures arrangements and procedures are established and maintained for receiving, documenting and responding appropriately to worker communications related to OSH. They ensure that the concerns, ideas and inputs of workers and their representatives on OSH matters are received, considered and acted upon. Each calendar quarter, the WOSH Committee reviews results of injury/illness investigations, performance indicator data, feedback from the Work Planning System, feedback from the Self Evaluation Program, Critiques and Occurrences and they are asked make appropriate recommendations from the workers' perspective.

3.5.4.Third-Party Certification Programs for Management of ESH

The C-A Department employs third-party certification for its Occupational Safety and Health (OSH) management system (MS) and its environmental management system (EMS). OHSAS 18001 (OSH MS) and ISO 14001 (EMS) are the standards used for third-party certification. The certification process and associated registration are discussed briefly below. Certification is the process by which a third party confirms, in writing, that an organization's management system meets the specified OHSAS 18001 or ISO 14001 requirements. Certification means C-A Department's management systems meet all requirements of the standards. The certification process involves an established framework of assessments. The certification body is the third party that actually assesses the organization's management systems. This certification body is often referred to as a "registrar" or certification company. Registration is the process by which the certification body, having verified that an organization's management system conforms to the standard, either OHSAS 18001 or ISO 14001, then includes or "registers" the management system in a publicly available list.

The certification process in general functions in the following manner. C-A Department or BNL selects a registrar to assess its management system. The certification body employs auditors to conduct the assessment. If the auditors determine that the OHS MS conforms to OHSAS 18001 or the EMS conforms to ISO 14001, then the certification body issues a certificate of registration that details the scope of the OSH MS or EMS. The information is made available to the public through a listing in a register or directory, and the C-A Department is entitled to display proof of certification. Certificates of registration are typically valid for three years, although this can vary depending on individual certification body requirements. Certification bodies typically conduct surveillance audits, essentially less-detailed assessments, on a six-month or annual schedule. When the certificate of registration expires, the certification body will typically conduct a complete reassessment, or conduct an assessment that is more comprehensive than the periodic surveillance audits.

The initial certification assessment consists of the following seven steps:

1. Identification of Scope and Management System Implementation: The C-A Department identified the site and scope of the certification effort. The Department conducted an initial review of its practices, processes and procedures to evaluate initial level of conformance with respect to OHSAS 18001 and ISO 14001. The Department then proceeded to implement the requirements of the standard. When the Department felt that it has successfully implemented management systems that met

the OHSAS 18001 and ISO 14001 requirements, it began the certification process by submitting an application to the certification body.

2. Application Submittal: The application submitted by the Department to the certification body identified the rights and obligations of both the certification body and the Department. The application addressed confidentiality issues, the right to appeal and dispute assessment findings, and instructions for use of the certificate of registration.
3. Document Review: Existing documentation relating to the Department's OSH MS and EMS was gathered and reviewed by the certification body in advance of the actual on-site assessments.
4. Pre-Assessment or Pre-audit: The pre-assessment was an on-site assessment that allowed the certification body to gain an initial understanding of the operations at the C-A Department and to have an initial look at the functioning of the management systems. The two main purposes of the pre-assessment, sometimes called a readiness review) were to prepare the involved parties for the ensuing process by providing a broad overview of operations and the audit process, and to determine the overall readiness of the management systems for a comprehensive assessment.
5. Assessment or Audit: Once it was determined that the existing management systems were at an adequate level to be audited, an assessment team visited the C-A Department. The assessment team was comprised of a lead auditor and several support auditors. The length of the on-site audit was about five days. During the assessment, the auditors verified that the C-A Department's management systems conformed to the OHSAS 18001 and ISO 14001 requirements through interviews

with key personnel, site inspections and review of management system documentation.

6. Certification: Three results were possible from this process: a) approval whereby the C-A Department’s management systems demonstrated acceptable conformance with the requirements of the OHSAS 18001 and ISO 14001 standards, b) conditional or provisional approval whereby the C-A Department’s management systems had minor non-conformances that can be easily rectified and reassessed within a specified period, and c) disapproval whereby the management systems did not demonstrate conformance with OHSAS 18001 and /or ISO 14001. Disapproval is typically issued in cases where basic elements of the standard, such as auditing or corrective action, have not been addressed at all. If C-A Department’s management system is ever disapproved, the Department must correct the deficiencies prior to the certification body conducting a reassessment.
7. Surveillance: To ensure that the Department's OSH MS and EMS continues to be in conformance after the initial assessment, the certification body will conduct periodic surveillance audits. Surveillance audits are typically conducted on a semiannual or annual basis, depending on the specific requirements of the certification body.

3.5.5. Calibration and Testing Summary for Engineered Safety Systems in Use

A standard set of calibration and testing requirements is used throughout the C-A Department complex to ensure the operational integrity of the Accelerator Safety Envelope. These requirements are set by authorities having jurisdiction, such as BNL’s Fire Protection

Engineer or BNL's Radiological Control Manager. The requirements for calibration, testing, maintenance, accuracy or inspections for engineered safety systems in use are as follows:

- the access control system is functionally tested in accord with requirements in the BNL Radiological Control Manual and testing does not exceed 12 months
- the beam instrumentation system is functionally tested in accord with requirements in the C-A OPM and devices are tested at beam startup and periodically throughout the running period thereafter
- building ventilation exhaust fans associated with ODH protection systems undergo annual functional testing, flow-rate measurements and maintenance and does not exceed 15 months
- fire protection/detection undergoes annual testing in accord with NFPA 72 and does not exceed 18 months
- area radiation monitors undergo annual testing that does not exceed 15 months
- radiological barriers undergo annual visual inspection and inspections do not exceed 15 months
- rainwater barriers for activated soil undergo annual visual inspection and inspections do not exceed 15 months

3.5.6. Administrative Controls for Routine Operation and Emergency Conditions

The administrative controls for routine operation and emergency conditions are:

Fire Hazards - Combustible material usage is kept to a minimum level, as dictated by the instrument and equipment needs. Substitution of non-combustible materials is done wherever feasible. Flammable materials cabinets are provided as required. The Experimental Safety

Review Committee reviews all combustible experimental materials. Fire hazards for the facility are addressed in detail in Fire Hazard Analysis documents.

Magnetic Fields - Magnets are used in the beam line. Any significant magnetic fields produced by these magnets are contained within beam line enclosures or limited access areas. Areas where the magnetic fields are greater than 0.5 mT (5 Gauss) are posted with warning signs for personnel with pacemakers or other medical implants. Medical evaluation and training of personnel with such devices is required before entry into the areas. Additional postings are used for fields greater than 600 Gauss, as per requirements in BNL's SBMS. Training and evaluation of work practices is required for all personnel expected to be exposed to magnetic field strength greater than 60 mT (600 Gauss). Training deals with the possibility of injury due to magnetic forces on objects.

Electrical Safeguards - Electrical safety implementation for design of equipment is covered by C-A Department OPM. Lockout/Tagout (LOTO) procedures are followed for areas where electrical hazards are present. Workers who perform work on electrical systems have LOTO training as specified by BNL. If it is necessary to work on any equipment while it is energized, a Working Hot Permit is issued.

Protective Clothing - Any use of chemicals, hazardous materials or cryogens requires review for personnel protective equipment. The clothing for a particular application is selected considering the expected hazards; a variety of clothing is likely to be needed to meet all hazards. Heat stress and flammability of protective clothing is considered in specifying protective clothing requirements.

Material Handling - All material handling is conducted in accordance with procedures in the C-A Department OPM and requirements in SBMS. Positioning of equipment may require the use of forklifts, overhead cranes and specialized lifting equipment. All personnel operating such equipment are appropriately trained. All material handling equipment is inspected by appropriate BNL personnel.

Elevated Work - Any work required at levels more than four feet above ground level undergoes Work Planning and fall protection evaluation.

Emergency Procedures - Emergency response is governed by procedures in Chapter 3 of the C-A Department OPM. The emergency plan covers possible hazards, emergency signals and expected responses. Each building at the C-A Department complex has signs posted indicating the emergency assembly areas, and the name and number of the Local Emergency Coordinator (LEC). The LEC is familiar with the hazards in the building, the utility locations and shut-offs, and any spill response supplies available. The LEC assists the Fire Rescue Group Incident Commander in responding to any incidents at the facility. Certain C-A facilities have separate emergency procedures in Chapter 3 of the OPM in order to document important, area-specific emergency information.

Radiation Protection – The radiation protection program at C-A Department is in accord with the BNL Radiological Control Manual[31], which in turn complies with Title 10 Code of Federal Regulations Part 835, Occupational Radiation Protection. The C-A Department OPM includes task-specific and RSC- and ALARA Committee-specific radiological procedures, which are used to implement the BNL radiological control system at high-energy particle accelerators.

Beryllium Exposure – Some beam-line vacuum pipes are made of beryllium, including bolts. Some of the water-cooled bases for fixed platinum targets are made of beryllium. These items are purchased and not machined on-site. Beryllium bolts are nickel coated to reduce the potential for airborne releases when bolts are loosened or tightened on beryllium vacuum pipes.

[31] https://sbms.bnl.gov/program/pd01/pd01t011.htm BNL Radiological Control Manual.

The exposure hazard is associated with handling beryllium items and the potential for creating airborne beryllium during this handling. SBMS requirements for beryllium are followed and the BNL Beryllium Use Review Form or its equivalent is used when beryllium handling is anticipated.

Asbestos Exposure – Asbestos is present in many buildings at C-AD, primarily in pipe insulation, ceiling tiles, gaskets, thermal insulation, cement boards and pipes, flooring material, and in roofing products. The location of asbestos areas is known. It may also be found in equipment such as in some older electrical wiring insulation. C-AD does not conduct operations that disturbs or removes asbestos. If asbestos-related work is anticipated, then C-AD contacts asbestos removal experts in Plant Engineering who use written exposure control procedures based on the SBMS Subject Area for Asbestos.

Lead Exposure – Lead (Pb) is encountered in the form of shielding in the beam areas. Handling Pb may be hazardous and C-AD requires the use of use protective equipment such as gloves. Pb may be found in brick, sheet or cast forms, or as wool that is used in Pb blankets. In most applications, the bare metal is covered or painted if practicable. Safety shoes are also required in addition to gloves when handling Pb bricks or sheets of Pb. C-AD staff do not shape, drill, or otherwise work with Pb in any way that causes it to become dispersible.

Shift Manning Requirements – The minimum number of shift operating personnel at C-A facilities during normal and emergency operations is specified in the C-A OPM. These minimums are also stated in the ASE.

3.5.7.Critical Operations Procedures

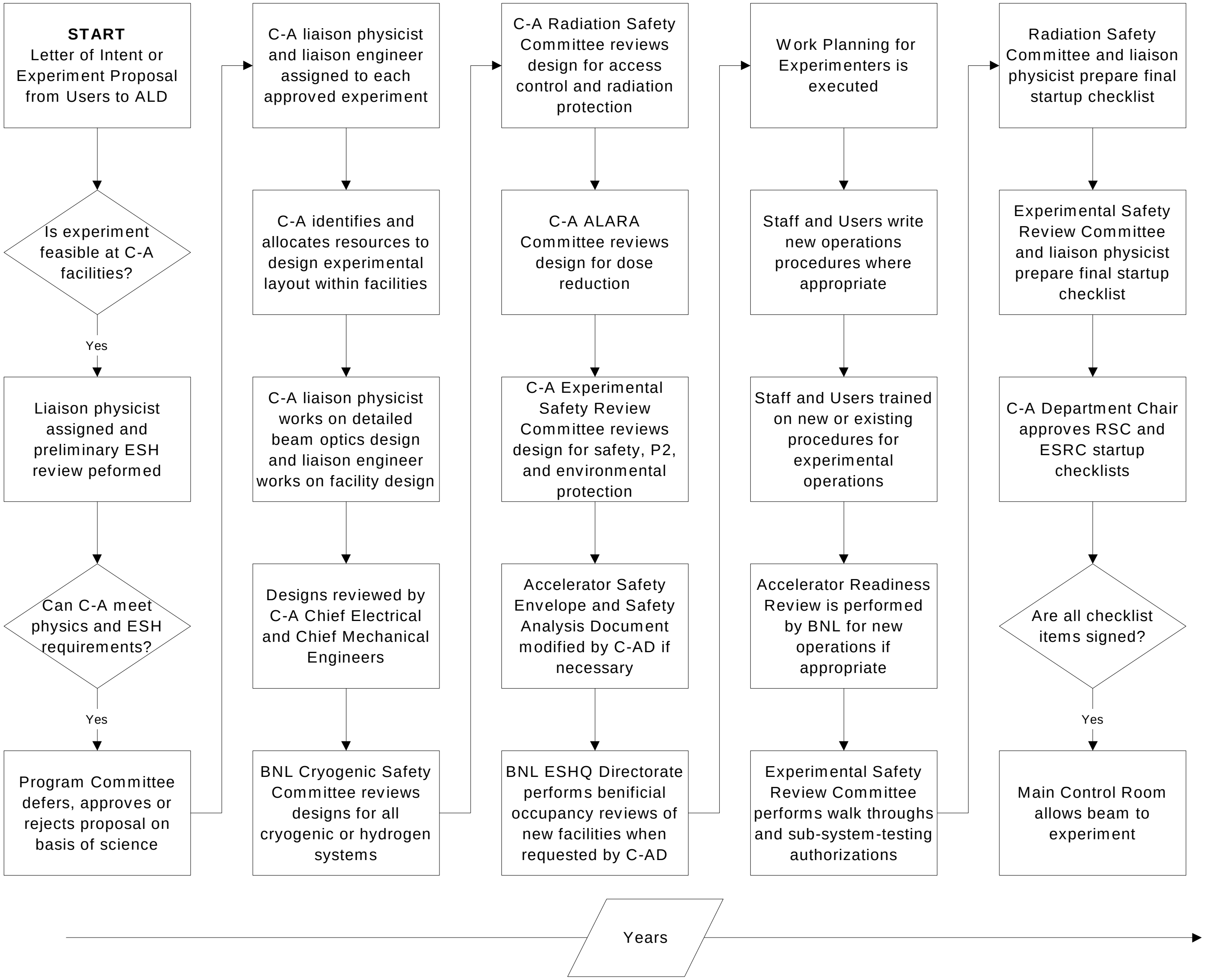
Specific operations procedures that prevent or mitigate accidents are related to resetting the Access Control System in order to enable beam from the MCR. These specific critical procedures involve clearing (sweeping) personnel from beam lines before enabling the beam line for potential operations. These procedures are found in Chapter 4 of the C-A Department OPM. The basic principles behind the authorization and use of these procedures are:

- wording must be consistent throughout the entire set of sweep procedures for the C-A Department; that is, specific terms must mean the same regardless of the location of the area being cleared of personnel
- before resetting for beam, it must be clear to the operator which sweep procedure from the set of sweep procedures applies under every access condition encountered in the field. If not, then the area is not reset for beam
- checklists are checked-off by the operations staff performing the sweep at the completion of each sequential step in the procedure
- annual re-training of operations personnel in access control procedures is performed
- new or modified sweep procedures must receive an independent review by the maintenance staff or their representative; these are staff normally cleared (swept) from the area
- if the Operations Coordinator assigns a gate watch to record access and egress, then the gate watch task is solely to count personnel into and out of the interlocked area; no other duties may be assigned to the gate watch such as checking training records or checking personnel dosimeters

3.6. Experiment Design Criteria

Liaison Physicists, Liaison Engineers, Experiment Spokespersons and members of the Collider-Accelerator Experimental Safety Review Committee (ESRC) have primary responsibility for reviewing an experiment to ensure it meets design criteria. Experiment review within the C-A Department has many steps. A flow diagram of the experiment review process is shown in Figure 3.6 and it applies to the experimental program as a whole. If there are no significant modifications or program changes to the experimental area during any given year, then the last 10 steps shown in Figure 3.6 are repeated before each running period. If proposed modifications or program changes to the experimental area exceed the limitations of the ASE, then the whole process represented in Figure 3.6 is repeated.

Figure 3.6 C-A Department Experiment Review Process



The C-A Department OPM experiment design criteria comply with SBMS requirements for planning and control of experiments. However, the term Liaison Physicist as used within the Department is equivalent to the term Experiment Review Coordinator as used in SBMS. The term Experiment Spokesperson is equivalent to the term Lead Experimenter as used in SBMS.

At C-A Department, an experiment or experimental area may lie dormant for a period greater than one year between runs and not require a review during the dormancy period. The Department reviews each scheduled experiment or experimental area before a running period. The running period may be continuous for many months and overlap a fiscal year or a calendar year. A second annual review would not be required if the experiment is in continuous operation for longer than 12 months and there are no significant changes to the experiment area. A running period significantly longer than 12 months is rare. If more than one running period occurs within a 12-month period, then review by the ESRC must occur for each scheduled experiment even if it results in a review of any specific experiment twice in one year.

The ESRC assures that the experiment's design does not exceed the approved ASE, or the scope and impacts described in any pertinent NEPA document such as the Environmental Assessment. For "critical" safety items, defined as items that must be closed out before start of operations of the experiment, the Liaison Physicist is responsible for ensuring closeout. The C-A Department Chair approves all experiment installation and the start of experimental operations before each running period.

Before the ESRC review, the Liaison Physicist, Liaison Engineer and/or the Experiment Spokesperson provide written descriptions of ESH issues and protective systems. Based on this written description, special subject-matter experts are called to join the ESRC for advice or review on an ad hoc basis. The experimenters are not allowed to operate or change experimental parameters beyond their approved envelope until satisfactory review by the ESRC. In addition, the Experiment Spokesperson must fulfill or resolve all pre-start ESRC recommendations and close all outstanding items. For changes beyond the approved envelope, the Liaison Physicist or the Experiment Spokesperson is responsible for notifying the ESRC Chair or the C-A Associate Chair for ESHQ, early in the planning phase.

For non-commercial experimental devices, the ESRC may request a certification of the device from the C-A Department's Chief Electrical Engineer or Chief Mechanical Engineer. Chief Engineer certification procedures are defined in the OPM.[32, 33]

The ESRC must ensure an environmental evaluation is performed for each experiment in conformance with requirements in SBMS. Any equipment or experimental materials with environmental aspects are examined. For example, the ECR to the C-A Department evaluates the potential consequences of a break in a buried pipeline, a spill onto soil or an accidental release to the air, sanitary sewer or storm drain, and any non-radioactive air emissions, radioactive air emissions, or liquid effluents.

Experimental procedures must comply with Conduct of Operations requirements for emergency procedures, operating procedures, training requirements and experienced staff during running periods. This is accomplished using the Work Planning for Experiments procedure in the OPM.

Pollution prevention is examined by ensuring experimental activities that involve purchasing, using or disposing of hazardous material or radioactive material is reviewed to reduce waste generation whenever possible. The ESRC considers measures to avoid or reduce the generation of hazardous substances, pollutants, wastes and contaminants at the source. The

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[32] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-02-03.PDF Procedure for Chief Engineers to Certify Conformance of Devices

[33] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-03-04.PDF Review and Approval of Electrical Equipment In-House

experimenters must have plans to reuse, if practical, hazardous material that cannot be eliminated, and have plans to treat the remaining waste to reduce the volume, toxicity or mobility before storage or disposal. The ESRC ensures that experimenters have identified a disposal path for all anticipated wastes before the experiment.

As a final point, the ESRC ensures that relevant Facility Use Agreements[34] are updated whenever affected by a modification to the experimental areas.

3.7. Characteristics of Experimental Systems Having Safety-Significant Functions

3.7.1. Experimental Systems Having Safety Functions at TVDG Target Rooms

Four separate target rooms exist in the facility. Three remain as active target rooms, and one, Target Room 3, is no longer in use as a target area. Several distinct beam lines are available in each active target room, providing a great deal of flexibility to experimenters. Covered trenches provide access to cable runs and utility services. Each room has a 30-ton steel shielding door for entry and exit from the main corridor. In addition, Target Room 4 also has an escape passage from Accelerator Room 2 located at its north-west corner. The shielding door is approximately 3 feet thick; the walls between adjacent target rooms are approximately 4 feet thick; the walls separating the target rooms from the corridor are approximately 6 feet thick.

The only fixed equipment in the three active target rooms are the beam lines and associated beam transport components. The fixed safety systems in the experimental areas are the access control system and emergency stop buttons. If a target room has not been

[34] https://sbms.bnl.gov/private/fua/fa00t011.htm BNL Facility Use Agreements

swept and secured prior to the onset of a radiation condition, or if a secure entry-point is violated with the target room in a secure condition, then the access control system will immediately insert a beam stop in the accelerator room to remove beam. Two separate beam stops are inserted. The redundant response removes beam from the affected target room. The system generates visible and audible signals on the system status panel indicating a "Radiation without Interlock" condition. A final level of personnel protection is provided for by the presence of emergency stop buttons located throughout the target rooms. These are large, illuminated, red pushbuttons labeled with "EMERGENCY STOP" signs. Should a person have cause, the one can activate the nearest switch.

Experiments in Building 901A are evaluated for potential safety hazards and environmental impacts in accordance with the C-A Department procedures. For experiments that are not initiated by outside users, the Principal Investigator or project manager is responsible for informing the appropriate C-A Department safety committee of projects requiring review and for providing necessary documentation. Outside users of the TVDG are required to complete a checklist that includes safety concerns. The TVDG Operation Supervisor brings any significant safety issues to the attention of the appropriate safety committee. The committees review safety related issues and make recommendations. Currently, other than access controls to the TVDG target rooms themselves, there are no experimental systems having safety functions at TVDG.

3.7.2. Experimental Systems Having Safety Functions at Booster's NSRL

For the majority of users at C-A facilities, biological safety is not an issue; however, it is an issue for programs at NSRL. Long-term experimental procedures with animals or biological materials are carried out in the user's own institution or in the BNL Medical Department or Biology Department; the C-A Department provides only short-term holding facilities for biological specimens.

The experimental systems that the users investigate at C-A facilities include:

- cultured non-human mammalian cells
- cultured human cells
- primary human cells such as small samples of blood obtained in medical facilities under Institutional Review Board[35] approval and transported to C-A Department by approved means
- isolated non-hazardous biological molecules, e.g., DNA
- standard laboratory animals such as Drosophilae (fruit flies), Nematodes (worms), chickens, rats and mice

Specific biological materials beyond those described here are reviewed on a case-by-case basis by the BNL IBC.

The potential for handling human blood dictates that a Biosafety Level 2 facility is provided. Biosafety Level 2 practices, equipment and facilities are appropriate when any work is

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[35] BNL Institutional Review Board (IRB) https://sbms.bnl.gov/ld/ld16/ld16d051.htm

done with human-derived blood, body fluids or tissues where the presence of an infectious agent may be unknown.[36]

For Biosafety Level 2, facility design specifies that the cell rooms are separated from general public access areas and hand-washing facilities are provided. To minimize external contamination of critical samples by increasing ease of facility cleaning and maintenance, scrub-able walls and poured-resinous seamless floors with closeable drains are specified.

All materials, including Regulated Medical Wastes, are transported by users back to the long-term facilities in the BNL Medical Department, and these transportation activities are reviewed and approved during experimental safety review by the ESRC. Transportation activities between C-A Department facilities and the Biology and Medical Departments are in accord with SBMS.

Safety equipment includes Class II biological safety cabinets to provide significant levels of protection to laboratory personnel and to the environment when used with good microbiological techniques as well as protect the experimental samples from external contamination. Personal protective equipment (PPE) such as laboratory coats, gloves and safety glasses are available. The Biological Safety Cabinet is appropriate for Biosafety Levels 2 and 3, but is not designed for volatile chemicals, as it re-circulates the air through a HEPA filter into the laboratory. Persons using blood or other tissues with the possible hazard of Blood Borne Pathogens receive appropriate training. All experiments using human cells and tissues are reviewed by the BNL IRB as well as the IRB of the Users' institutions, as appropriate.

Laboratory-animals are kept at C-A Department for less than 24 hours and for USDA regulated species, they are kept less than 12 hours. Exceptions to this 24 hour/12 hour rule may

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[36] Biosafety in Microbiological and Biomedical Laboratories (BMBL) 4th Edition, HHS, CDC, U.S. Government Printing Office, April, 1999 http://www.cdc.gov/od/ohs/biosfty/bmbl4/bmbl4toc.htm

be approved by the Institutional Animal Care and Use Committee (IACUC) on a case by case basis.[37] The animal facility is designed and constructed to facilitate cleaning and housekeeping. This includes poured-resinous, seamless floors and washable walls. The facility has its own entrance, and the wing of the building containing the animal facility is closed from the general corridor by double doors. The facility has its own air handling system, which is vented away from the intakes of the other air handling systems. No studies of infectious agents are anticipated at C-A Department. Animals and cages are returned to the BNL Medical Department. Hot water hoses are used for washing animal racks at the animal facility.

There is no need to prohibit animals from the facility in case of ventilation problems due to the limited amount of time animals will be housed there. The facility has locks on the doors and a card reader at the entry. All personnel entering the animal facility have previously been issued keys or key cards, and placed on a facility access list.

Current users have not proposed the use of recombinant DNA materials at BNL. In the context of the National Institutes of Health (NIH) Guidelines, recombinant DNA molecules are molecules that are constructed outside living cells by joining natural or synthetic DNA segments to DNA molecules that can then replicate in a living cell. Although improbable, some recombinant DNA may cause serious or lethal human disease. If use of recombinant DNA materials prepared at a user's home institution is proposed, then the user must submit a copy of the home institution's Institutional Biosafety Committee (IBC)[38] approval. Additionally, a copy of the risk assessment analysis, a transportation plan in accord with DOE and International Air Transportation Association rules, and a description of the material must be forwarded to the BNL IBC for their consideration and approval before approval to bring such material to the NSRL is

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[37] Unreviewed Safety Issue, http://www.rhichome.bnl.gov/AGS/Accel/SND/USI/NSRLUSI.pdf
[38] Institutional Biosafety Committee HTUhttps://sbms.bnl.gov/ld/ld16/ld16d341.htmUT

given. It is unlikely that recombinant material will be constructed at BNL; however, any such experiments would be reviewed by the BNL IBC and NIH Guidelines shall be followed.[39]

Transportation of experimental samples/equipment, etc. to or from BNL is by DOT rules; experimental investigators are informed of this requirement when they register via the BNL Guest Information System. On site transportation of user's equipment, radioactive materials, regulated medical waste and biohazards, is performed after appropriate packing, labeling and documentation of the material, according to BNL requirements in SBMS.

3.7.3. Experimental Systems Having Safety Functions at AGS Fixed Targets

The potential hazards associated with fixed target experiments include radiation, high voltage, high current, cryogenic conditions, mechanical hazards due to massive components, flammable gasses, lasers and high vacuum. Radiation safety requirements for specific experiments are established and posted for each experimental area, and users are trained on how to use the Access Control System associated with their experiment. In addition to the hazards of contact with energized electrical circuits, the short-circuit capacity of the 120/208 and 480-volt systems is much above that encountered at most industrial and/or research facilities. Therefore, connection and disconnection to a C-A power distribution system is made only by qualified BNL personnel. Central power shutdown switches are designed for each experiment should they be needed in the event of a local fire or similar emergency. Experiments requiring radiation or ODH interlock functions have these safety systems as an integral part of the Department-wide ACS that was previously described.

[39] NIH Guidelines for Research Involving Recombinant DNA Molecules http://www4.od.nih.gov/oba/rac/guidelines/GUIDELINjan01rev.pdf

The use of liquid hydrogen occurs occasionally in high-energy fixed target experiments. When an experiment involves the use of liquid hydrogen, all work associated with this flammable cryogenic fluid is performed by qualified BNL personnel. The experiments may use several liters of liquid hydrogen as a fixed target. Cryogenic target enclosures are sufficient to contain and vent the hydrogen should target containment fail. Automatic fail-safe venting is designed to occur should a fire break out near the target, should a power failure occur or should a leak develop at the target or target vacuum. Safety review of the design and a design analysis for hazards are performed for each target. A cryogenic target watch is assigned round-the-clock during operations with liquid hydrogen targets.

The targets are located in secondary beam lines typically upstream of spectrometer magnets. The support stands for the targets generally allow them to move several feet out of the beam. Target controls, monitoring and hydrogen detection is located downstream typically at the downstream side of the dump shield for the secondary beam line. Dump shields for these beams are typically eight-foot high, four-foot thick concrete blocks.

The target vessels have upstream and downstream windows that are typically 6 inches in diameter and constructed of 0.006-inch thick aluminum epoxy laminated with typically 0.01-inch thick Kevlar mesh. Targets are surrounded by Herculite and aluminum sheet metal enclosures with 6-mil Mylar windows for the experimental beam. The enclosure allows air to be drawn past the target equipment and vented into the low-pressure target vent system. The enclosure is designed to contain the hydrogen or deuterium in the event of a total failure of the target system. The electrical equipment inside enclosures meets Class I Division II standards for electrical circuits in explosive atmospheres.

There is no full-time occupancy within an established over-pressure zone near a hydrogen target and equipment racks and monitoring stations are typically more than 30 feet away. These zones are considered low-occupancy areas. Experimenters and watch personnel may walk by or briefly work in the zone; typically, one or two people at a time. In the event of an accidental explosion, peak over-pressures are likely to be significant to move large magnets nearby, collapse the target enclosure and collapse nearby experimental detectors. The nearby secondary beam dumps will likely remain standing.

Safety features include testing target windows against puncture, interlocking the target vacuum sensor and hydrogen detectors to the power supply to nearby experimental detectors, and protecting upstream and downstream experimental detectors and chambers with fire wire and smoke detectors. The fire wire and smoke detectors will interlock the electric power to the experiment and cause alarms to go off alerting both MCR operators and the target watch.

Before a target installation, the environment around the target is reviewed for potential ignition sources. Pre-amps, cabling, power-supplies, gas flow systems, detectors and detector chambers are typically examined. Safety requirements call for written procedures to operate experimental chambers and gas systems around the target. They also call for routine portable sampling for hydrogen or any other flammable gas in use near the target before startup and following shutdown. Voltages on experimental equipment are normally required to be present before hydrogen or deuterium is introduced to the target. Alarm responses are written into formal procedures and the target watch is trained, again before the introduction of hydrogen or deuterium to a target.

Work on or around the target is forbidden unless the hydrogen or deuterium is removed. Fire wire and smoke detectors are required to be operational at all times. Failed smoke detectors are not allowed to be bypassed while the target is in operation.

All lasers in the experimental areas are reviewed by the BNL Laser ESH Officer before initial use or following modification to a previously reviewed laser. Users meet specific requirements, including medical surveillance requirements, established for the laser. Interlocks are from either the laser manufacturer or part of the ACS.

Potential energy hazards are those associated with compressed gases and vacuum windows, as well as those associated with hoisting and rigging operations. These hazards are mitigated by safety reviews and compliance with SBMS and all applicable codes. For large vacuum windows, mechanical methods for controlling access to the window are employed since hearing damage or other injury may occur upon window failure. A metal shutter is used to protect the window during work near the window, and certain shutters are set up to be inserted before entry into the experimental beam line, and extracted when the beam line is in operation.

3.7.3.1.Experimental Area Group Alarm (EAGAL) System

The EAGAL system is designed to transmit alarms from the Target Desk to Main Control and the Collider-Accelerator Systems (CAS) watch. Originally, the Target Desk in Building 912 was continuously manned when the AGS was operating. To more efficiently use the CAS watch the Target Desk alarms were automated to the Main Control Room. This enabled Main Control Room operators to take corrective action themselves or to use the radio to contact the CAS watch. The original automated alarm system was custom-built electronics that had become obsolete and very difficult to repair. Recently, it has been replaced with an Allen-Bradley PLC system.

The Target Desk alarms cover a wide range of possible inputs and outputs. The system has evolved to be adaptable to the varying needs of the experimental areas. Experimental equipment alarms that are routed through the Target Desk and then EAGAL to Main Control include:

- flammable gas detection, bypasses and resets
- emergency generator alarms and resets
- magnet cluster-lockouts
- hydrogen target alarms
- building fan controls
- building evacuate
- crane power controls
- magnet cooling water status
- beam line vacuum alarms
- shield top access key status
- miscellaneous alarms that are requested by the experimenters

Although specific equipment is discussed in the following, alarm system components may vary in the future as technology warrants. Target Desk alarms are input to an Allen-Bradley SLC-5/04, which is located in Building 940, through remote input-output blocks that are located on the first floor of the Target Desk. The alarms are sent via a remote input-output link to a PLC-5/V40B that is located on the second floor of the Main Control Room in Building 911. The PLC-5/V40B is an Allen-Bradley PLC, which resides in a VME chassis. This is the connection to C-A Controls for recording of alarms and displaying of alarms in the Main Control Room. As a back up, the alarms are also sent by separate line to Panel View display screens in Main Control and Building 940, where the CAS watch resides. There is a continuous “heart beat” signal between the SLC-5/04 and the C-A Controls. If this link is lost, then an alarm will display on the C-A Controls screen and the Panel View screens.

Currently, and at most times, the majority of the possible 768 alarms through EAGAL are masked off. This is due to the ability to handle flammable gas and hydrogen targets at many locations in Building 912, which were not in use at the time of this writing. When an alarm is masked, the status is not displayed on the EAGAL system. This is done to avoid nuisance alarms from sensors that may drift during a long period when they are not in use.

3.7.4.Experimental Systems Having Safety Functions at RHIC Intersecting Regions

The potential hazards associated with experiments at the RHIC IRs include radiation, high voltage, high current, mechanical hazards due to massive components, flammable gasses, lasers and high vacuum. As is the case with fixed target experiments, radiation safety requirements for specific experiments are established and posted for each experimental area, and users are trained on how to use the Access Control System associated with their experiment. In addition, connection and disconnection to a C-A power distribution system is made only by qualified BNL personnel. Central power shutdown switches are designed for each experiment should they be needed in the event of a local fire or similar emergency. Experiments requiring radiation interlock functions have these safety systems as an integral part of the Department-wide ACS that was previously described.

While some experimental hazards can be categorized as routinely accepted, others are classified as experiment specific hazards that require safety systems. In particular, PHENIX and STAR experiments have systems with safety functions specific to their experiments for equipment protection. Alarms from systems with safety functions at RHIC experiments go through systems similar to EAGAL in that they are interfaced to C-A Controls through PLC-5/V40 interfaces at each IR.

PHENIX is a complex system with potential hazards typical of large detector systems. PHENIX has adopted the approach of providing a Safety Monitor and Control System (SMCS) that continuously polices the PHENIX sub-systems and local environment inside the PHENIX Experimental Hall. The PHENIX SMCS is an active, real time, monitoring and control system that takes inputs from gas, smoke and fire detection systems as well as the emergency crash button circuit. It can also accept a crash signal from any one of the PHENIX sub-systems.

Upon detection of an off-normal situation from any input, or activation of a crash button, the SMCS can respond by tripping a master contactor that will reach back to the power breakers and remove all clean and utility power inside the hall. In parallel with the power shutdown, the SMCS can also initiate the following actions:

- shutdown of detector gas and initiate a safe purge
- signal to PASS and activate emergency exhaust fans and HVAC
- communicate and alarm to the local Fire Control Panel
- communicate and alarm to MCR
- communicate and alarm to PHENIX Control Room

The SMCS receives its electrical power from an independent, non-common branch circuit. The branch circuit is tied into the Emergency Power System, which is a diesel generator, to assure continuous operation during long-term power outages. A UPS protects against dips and short-term interruption.

Much of the electronics in PHENIX is housed in enclosed racks mounted on the carriages and magnets. These racks contain high voltage for the detectors, low voltage power for the on-detector electronics, as well as some detector electronics. These racks have an internal interlock system capable of sensing temperature, smoke, coolant loss and local manual crash. They can also be powered off by remote control.

Detector gas systems, either recirculating or single-pass, during normal operation continually take make-up gas while venting an equal amount outside the IR through the Low Capacity Vent Stack. Exhaust pipes vent to this 30" diameter shaft in the South West corner of the IR about twenty feet up the West wall. A special fan arrangement ensures a constant and steady backpressure for all systems and dilutes the mixture of all flammable gases to less than 25% of the Lower Explosive Limit. This fan runs continually during operations with gas and is interlocked. A second and similar stack in the North West corner is used for off-normal modes of operation such as detector purges, overpressure venting, and emergency pump-downs. The stack ducting and fan exhaust is strategically oriented to vent stack gases away from potential sources of ignition and building air-handler intakes. The vent stacks satisfy the criteria for venting of flammable gases.

The STAR experiment has a series of interlocks both in the overall STAR integration program and in each experimental subsystem. Typically, interlocks include smoke and heat detection, gas detection, and water leak detection. Depending on the detector activated, the interlock system has the capability of isolating electrical power to an experiment rack or isolation of the entire experimental and magnet electrical system. The interlock system can also initiate a purge of the flammable gas system.

4. Chapter Four, Safety Analysis

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4.1. Introduction

The design of the Collider Accelerator Department's suite of ion injectors, accelerators, the collider and the experimental facilities is based upon the experience and successful designs employed since the initial startup of the AGS in 1960. The basic approach for the safety analysis has been to review the potential hazards for each major segment of the facility. Hazard analysis is the standard method for applying the DOE graded approach for minimizing risk. It is well suited to identifying and understanding risk because it requires consideration of both the likelihood and the potential consequences of hazards. The product of likelihood and consequence constitutes the risk. When using risk as the measure of acceptance, the allowable consequences for lower likelihood events are higher than for the higher likelihood events. In the hazard analyses presented in this chapter, the approach has been to evaluate the risk and to identify preventive and mitigating features and controls that ensure that risk is acceptably low. Because the suite of facilities follows consensus codes and standards, standard industrial hazards are adequately addressed and their risks minimized without the need for detailed hazard analyses.

4.2. Hazard Analysis Approach

Hazard analyses include hazard identification and screening, assessment of the potential consequences of unmitigated risk, identification of relevant and effective mitigation/preventive measures, and finally, assessment of mitigated risk. Hazard analysis makes it possible to understand the risk and make informed risk acceptance decisions. It is desirable to be able to show that the C-AD Facility risks are in the "extremely low" category (see Table 4.2), and an effort to do so has been made in this section of the SAD. The hazard identification process used the C-AD Facility design and operating information; BNL site documents; facility walk-downs to identify potential hazards within the complex that could adversely affect the workers and environment; and discussions with the engineers and users of the facilities. The hazards evaluation process is a largely qualitative assessment of potential accidents or impacts in terms of hazards, initiators, likelihood estimates, preventive or mitigating features and public, environmental and worker consequence estimates. A maximum credible accident scenario for each major portion of the complex is presented later in this chapter, the consequences of which bound all those to workers, the public and the environment. The results of these analyses confirm that the potential risks from operations and maintenance are extremely low. The hazards involve those present at all high-energy ion accelerators and experiments such as radiation, chemical, biological, electrical, magnetic fields, rf fields, energy sources, pressure and vacuum, material handling and lifting, heights, rotating equipment, fire, explosions, natural phenomena, steam, heat and cold, confined spaces, lasers, compressed gas, hazardous materials handling, etc. There are no unique hazards that are not addressed in a safe and efficient manner.

Table 4.2 The Risk Matrix

Consequence Level

High (Note 1)	Low Risk – Acceptable	Medium Risk-Unacceptable	High Risk-Unacceptable	High Risk-Unacceptable
Medium	Extremely Low Risk - Desirable	Low Risk – Acceptable	Medium Risk-Unacceptable	High Risk-Unacceptable
Low	Extremely Low Risk - Desirable	Extremely Low Risk - Desirable	Low Risk – Acceptable	Medium Risk-Unacceptable
Extremely Low	Extremely Low Risk - Desirable	Extremely Low Risk - Desirable	Extremely Low - Desirable	Low Risk – Acceptable
	Extremely Unlikely ($<10^{-4}$/y)	**Unlikely (Between 10^{-4}/y and 10^{-2}/y)**	**Anticipated (Note 2) Medium (Between 10^{-2}/y and 10^{-1}y)**	**Anticipated(Note 2) High ($>10^{-1}$y)**

Likelihood of Occurrence

Note 1: Definition of Consequence Levels -

- Extremely Low: Will not result in a significant injury or occupation illness or provide a significant impact on the environment.
- Low: Minor onsite with negligible or no offsite impact. Low risk events are events that may cause minor injury or minor occupational illness or minor impact on the environment.
- Medium: Medium risk events are events that may cause considerable impact onsite or minor impact offsite. Medium risk events may cause deaths, severe injuries or severe occupational illness to personnel or major damage to a facility or minor impact on the environment. Medium risk events are events from which one is capable of returning to operation.
- High: High-risk events may cause serious impact onsite or offsite. High-risk events may cause deaths or loss of facility/operation. High-risk events may cause significant impact on the environment.

Note 2: 10CFR835 may require limits that are more stringent for anticipated events.

4.3. General Approach to Risk Minimization

Hazard identification produces a comprehensive list of hazards present in a process or facility, and the screening phase removes all hazards that are below a threshold of concern, or that are covered by recognized industrial codes and standards. The hazards that are "screened out" do not need to be studied in detail because their risks are already well understood and acceptable. This process is a creative, multi-person examination of the processes, operations and experiments related to C-AD facilities. A hazard is a source of danger with the potential to cause illness, injury or death to personnel, damage to an operation or cause environmental damage.

For each screened hazard retained for further detailed hazard analysis, the unmitigated risk is first evaluated in terms of likelihood and consequence. This evaluation is performed using professional engineering judgment based on machine and experiment design and operating history. This places the hazard on the risk matrix (see Table 4.2). The following assumptions govern the determinations of unmitigated risk:

- The unmitigated risk does not include safety or control systems.
- Assigned frequencies are based on engineering judgment.
- Assigned consequence can be qualitative, but must be conservative.
- If the unmitigated risk is extremely low, then the analysis can stop at this point. Otherwise, one proceeds to the evaluation of mitigated risk as described below.

The unmitigated risk is reevaluated considering the preventive and mitigating factors in place that would either reduce the consequence or reduce the frequency. This should move the location on the risk matrix based on assumed conditional probabilities of failure for the mitigating systems. At this point, the mitigated risk should be either low or extremely low. For low risk, the evaluation of the hazard is reviewed to determine if there are additional preventive or mitigating features that could be credited to bring the risk to extremely low. The last step is to determine if it is necessary to designate any Safety-Significant equipment, make commitments for formal administrative controls, or specify limits for operation. Safety-Significant equipment is designated as such because it actively or passively protects workers and/or staff from significant hazards.

The purpose of Safety-Significant designation is to highlight a minimum number of structures, systems or components needed to ensure safety. The number of designated Safety Significant items and administrative controls and limits must be minimized so that they can be treated specially and considered for incorporation in the Accelerator Safety Envelope (ASE), appropriate procedures and/or quality assurance documents.

If the unmitigated consequence is fatal for one or more persons or a significant environmental impact can occur, then a Safety-Significant designation, in general, should be made. If there are several mitigating or preventive features, and any single one can control the hazard adequately, then it may not be necessary to designate a Safety-Significant feature.

Table 4.2 allows binning of the hazardous event by its risk, which is a combination of the consequence of the hazardous event and its likelihood of occurrence. Some of these combinations are deemed acceptable, meaning these lower risk bins are adequately addressed by the qualitative hazard evaluation process. Other, higher risk bins are labeled unacceptable because the accidents within these bins require additional quantitative analysis to determine the true mitigated risk.

4.4. Risk Minimization Approach for Radiation Hazards

The risk of a serious radiation injury at BNL accelerators and experiments is insignificant. However, for radiation exposure it is customary to go beyond the scope of Hazard Analysis to demonstrate that transient events, such as credible beam faults, do not cause annual radiation dose goals or requirements to be exceeded. The special status of radiation hazards is exemplified in the As Low As Reasonably Achievable (ALARA) requirement in the BNL Radiation Control Manual that exposure to radiation is to be minimized and driven as far below the statutory limits as is practicable. Some areas are controlled access areas. These areas (Controlled Area, Radiation Area, etc.) are established to control the flow and behavior of workers in each area such that workers receive the minimum radiation exposure coincident with operating and maintaining the facility, which is the risk, to achieve its authorized research mission, which is the benefit. These areas are set with the expectation that radiation levels will not exceed certain specified maxima depending on the type of zone. The designated area maxima will be satisfied considering both the base level of residual radiation fields and the integrated effect of the short bursts typical of credible beam faults. The C-A Operations Procedure Manual, in compliance with the BNL Radiation Control Manual, lists the different areas including the required controls for minimizing exposure to external radiation. Significant contamination and internal uptake of radionuclides at C-AD facilities is extremely unlikely. Further analyses of these issues are not necessary, and are documented in a Technical Basis for Bioassay.[1]

[1] Technical Basis for Bioassay Requirements, Collider-Accelerator Department, January 2001.

4.5. Hazard Identification and Hazard Analysis

This section describes the hazard identification and qualitative hazard analysis for each of the major portions of the C-AD accelerators and experiments: injectors, accelerators, beam transport systems, beam stop systems, targets, support buildings, power supply buildings, cooling water systems, cryogenic systems, vacuum systems, shielding and instrumentation systems. The results of the hazard identification and analyses are given in Appendix 2.

The hazard identification process examined the C-AD facility processes, operations and maintenance that could result in a source of danger with the potential to cause illness, injury or death, damage to operations or environmental damage. The facilities design documentation, BNL conventional and radiological safety requirements, facility walk downs, C-A Operating and Emergency Procedures, and discussions with engineering staff, experimenters and safety professionals were utilized to conduct the detailed hazard identification and hazard analysis.

4.5.1. Conventional and Environmental Hazards

A review of all safety and health issues related to C-AD facilities leads to the conclusion that fire including explosions, radiation, oxygen deficiency hazards from large quantities of inert gases and electrical hazards require further safety analysis, which considers the preventive and mitigating facility design features. Hazard screening is documented in Appendix 2.

Pressure and vacuum vessels, use of toxic, hazardous and biological materials, use of small quantities of flammable/inert/cryogenic gases/fluids, noise, hoisting/rigging, confined space entries, lasers, rotating equipment, heat and magnetic fields are considered routine activities. The risks from these activities are maintained acceptable by compliance with the requirements of the BNL Standards Based Management System (SBMS) Subject Areas and the C-A Operations Procedure Manual. When required, these hazards undergo review by the appropriate BNL or C-AD committee or they undergo review by C-A ESHQ Division specialists during the work planning process, as indicated by C-A OPM or SBMS requirement.

Because of special focus on beryllium, lead and asbestos hazards, details of the programs controlling these hazards are summarized. The inhalation of beryllium dust or particles can cause chronic beryllium disease (CBD) and beryllium sensitization. The Department of Energy has established regulations to require a chronic beryllium disease prevention program (CBDPP) for certain work conditions. The goal of the CBDPP is to reduce the number of workers currently exposed to beryllium, minimize the levels of exposure to beryllium, and establish medical surveillance requirements to ensure early detection and treatment of disease. In 1997 and 1999 BNL conducted reviews of the use of beryllium on-site. These evaluations determined the applicability of BNL current operations to DOE regulations and led to the establishment of BNL policy on the use and handling of beryllium. Certain work at C-AD facilities involves beryllium. For this work, in accordance with BNL SBMS, a beryllium use review form (BURF) is required. These forms provide the precautions to be followed, PPE requirements and spill, release and cleanup plans for beryllium use and handling activities.

Lead is a toxic substance that, if not handled properly, can create adverse health effects. The inhalation or ingestion of lead dust or particles can cause permanent health effects in children and adults. The OSHA, HUD, and EPA have established regulations to require a lead exposure prevention program for certain work conditions. The goal of these requirements is to reduce worker levels of exposure to lead, establish medical surveillance requirements to ensure early detection and treatment of disease, and minimize releases to the environment. Procedures describe measures such as PPE to enable compliance with these regulations and to prevent worker injuries and illnesses from working with lead.

Asbestos may be present in many buildings at BNL, primarily in pipe insulation, ceiling tiles, gaskets, thermal insulation, cement boards and pipes, flooring material, and in roofing products. It may also exist in brake and clutch linings. It may also be found in some laboratory equipment (such as insulation on gloves, ring stand clamps, and heating mantles), fire blankets, and some older electrical wiring insulation.

Asbestos sampling and removal are highly regulated by government agencies such as the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA). Conducting any operation that disturbs or removes asbestos requires written exposure control procedures that are approved by the BNL asbestos subject matter expert.

These procedures provide information on how to identify, sample, remove, dispose of, and work with asbestos-containing materials. This information ensures compliance with OSHA while protecting workers and building occupants. The procedures also provide information for the types of documentation that are involved in asbestos work. Asbestos workers must receive training that complies with the OSHA and EPA model training program curriculum.

Under certain conditions, usually associated with heavy occupational exposures over prolonged periods, asbestos can lead to diseases such as asbestosis, mesothelioma, and lung cancer. Based on both animal and human studies, asbestos is classified as a Class I carcinogen (known to be human carcinogens) by the International Agency for Research on Cancer (IARC). The nature of the risks of asbestos exposure vary according to the duration and intensity of exposure, the type of fiber, and other critical factors. By controlling airborne fiber release and exposure to workers and building occupants, the risk of these asbestos diseases can be greatly reduced.

Electrical safety is a serious and complex subject, which is controlled by trained and experienced C-A and BNL staff engineers, operators, technicians and maintenance personnel. A full description of the electrical safety requirements that assure electrical safety is given in the BNL SBMS. At times access to the injectors, accelerators, transport lines, target areas and the collider is allowed when the magnets are powered. However, access to these areas is always controlled and limited to properly trained individuals. A C-A OPM procedure and an approved working hot permit cover access to these areas by trained and authorized C-A support staff to investigate problems.

Static or fringe magnetic fields that are present in the facility magnets do not warrant special controls other than appropriate warning signs and training of personnel who have access to the areas in accordance with the requirements of the BNL SBMS.

Lists of chemicals used in the C-A facilities including the manufacturer's Material Safety Data Sheets are maintained in accordance with the BNL Chemical Management System. Required reviews of the conventional safety aspects of the C-A facilities shows that use of these chemicals does not warrant special controls other than appropriate signs, procedures, appropriate use of personal protective equipment, and hazard communication training, all of which have been implemented. Reviews are carried out before work begins, via the work planning process.

With regard to environmental impacts, the effluent hazards include generation of ^{3}H and ^{22}Na in the earth shielding, which could potentially contaminate the ground water, and generation of short-lived radioactive gases in the air in the accelerator rings, transfer lines, tunnels and target caves/rooms. Both of these are addressed in this Chapter of the report, and these hazards have been eliminated or controlled by design. When required or at the discretion of management as a best management practice, Suffolk County Article 12 Code is followed in the design of cooling water systems and piping that contain tritium, sodium and other radionuclides. Diversion of radioactive liquid effluent from the sanitary waste system to a hold-up system, or hold up of radioactive liquid in C-A facility sumps, occurs in order to allow retention and sampling before disposal. Air emissions from C-AD facilities are negligible since the potential activation products are sufficiently low; that is, much less than 0.1 mrem/year to the public, to assure doses are ALARA. Results of environmental monitoring and details on exposure pathway analysis are found in the annual BNL Site Environmental Report produced by the BNL Environmental and Waste Management Services Division.

4.5.2. Radiation Hazards

The BNL accelerators and experimental beam lines have been in operation for over 45 years providing protons and polarized protons for the high-energy physics program, and in addition, for the past 15 years, the accelerators have been providing heavy ions for the nuclear physics and NASA programs. Among the three operating modes of the AGS, high flux unpolarized proton beam, polarized proton beam and heavy ion beams, the high flux unpolarized proton operation represents the greatest ionizing radiation hazard because it provides the highest intensity beam. Beam fault calculations for shielding and activation are based on fluxes associated with unpolarized protons. For radiation dose calculation purposes, each nucleon in a heavy-ion nucleus, either proton or neutron, is treated as an independent high-energy particle.

There is a great diversity in the type and energy in the ion beams used at the C-AD facilities. The primary beam is only present when the machines are operating. Before interacting, the accelerated beam is essentially monoenergetic, consisting of only one particle type. Passage through the accelerator equipment, experimental equipment or thin shielding leads to the development of electromagnetic and hadronic cascades, which produce many particle types, distributed over a wide range of energies. As the beam energy increases, a greater diversity of secondary particles exists in the primary area radiation fields. Inelastic spallation reactions become significant at energies above ~1 to 3 GeV. Accelerated and/or circulating beam losses occur as the beam changes direction, during beam injection into and beam extraction from a machine, at collimators and when the beam passes through transition energy in the AGS and RHIC. As these losses occur when the machine is operating, the problems of radiation protection outside the shielding are dominated by photons, neutrons, and for primary energies greater than ~10 GeV, muons.

Typically during high intensity proton operations, the neutron dose to C-AD staff is less than 10% of their total annual dose. Experimenters and operating personnel who are near the shielding during machine operations receive the higher neutron doses. Heavy ion beam operations do not result in neutron dose to personnel.

The primary ion beams, secondary pions and neutron beams, and scattered particles induce radioactivity in the machine components, targets, collimators, beam scrappers and dumps, shielding including soil, cooling water and nearby equipment. The interaction of the hadronic beam with these components produces an inelastic cascade. The particles produced in the materials during the spallation are followed by the evaporation of nucleons from the excited residual nuclei. The full spectrum of isotopes from the original target material nucleus down to tritium may be produced, but in practice only a small number of products are important because of the production cross-section values and radioactive half-life values. This volumetric activation within solid materials requires radiation surveys and radiation controls during entry into these areas following machine shutdown for inspection, maintenance or repair activities. The residual radioactivity produced in cooling water is minimized by passing the water through filters and deionizers, which reduces most activation products except for tritium. With the exception of targets, collimators, beam dumps and scrappers, or machine injection and extraction components, the specific activity is not high. Because of the significantly longer mean free path between interactions, the extent of the activity is widespread, dilute and dispersed; unlike activated materials at reactor facilities. This fact greatly reduces the potential for significant contamination issues at C-A facilities.

Muons arise from the decay of pions and kaons, either in secondary particle beams or in the cascades produced by high-energy hadrons. Muons are weakly acting leptons that deposit energy in materials by electroweak interactions, or ionization with atomic electrons and can only be removed by ranging them out. For example, at 30 GeV, the muon range is ~80 m in soil, ~60 m in concrete and ~20 m in iron. They can have an energy spectrum that varies up to the energy of the parent pions. Thus, shielding design for muons completely dominates the forward shielding requirements. Muon dose is measured by use of standard health physics instrumentation, because they are similar to electrons in every respect, including quality factor, except for their heavier mass.

The principal radiation hazards at C-AD facilities derive from the primary beam flux and duty cycle of the machine. Listed in order of importance, these hazards include:

- inadvertent exposure of workers to primary beam
- exposure to prompt secondary radiation created by primary beam losses during normal operation or episodes of abnormal losses, including areas near labyrinths and penetrations
- exposure to residual radiation induced in machine components such as beam scrappers, beam dumps, collimators, extraction magnets, targets, etc
- inadvertent release of activated cooling water to the environment
- inadvertent release of radioactive contamination to groundwater by allowing rainwater to leach through activated soil shields
- exposure to activated air from primary and secondary beam
- sky shine

4.5.3. Source Terms and Calculated Radiation Fields

In estimating the degree of radiation risk, the shielding is designed assuming the routine and maximum operating beam for the each accelerator and experimental facility. The shield is designed to mitigate the greatest radiation hazards, which are unpolarized protons. Thus, the shield is more than adequate for protection against polarized proton or heavy ion loss because their intensity and/or individual nucleon energies are much less by comparison.

A baseline evaluation of radiation hazards associated with operation and construction of the accelerator and experimental facilities is included as Appendix 2. Specifically, estimates of the following hazards are given here:

- exposure to primary beam
- prompt radiation immediately outside the primary beam shielding
- exposure to residual activity
- activated cooling water
- potential contamination of groundwater from activated soil
- air activation
- sky shine

Details for each facility are given in the following sections. It should be noted that the computed dose rates given in the following sections for each accelerator and experimental facility are conservative and actual dose rates found during facility operations are well below these estimates. The calculations are documented below and in each of the original SADs to show the process that is followed in commissioning a facility. Conservative dose estimates are made to determine the shielding, soil capping, radiological posting, access controls and air emission monitoring requirements during the design phase of a project or facility modification. Post construction/modification beam fault studies are conducted as appropriate to ensure that the designs are adequate. Records of these studies are maintained. Finally, during accelerator and experiment operations at full intensity the following monitoring assures that the facilities are operated within their approved safety basis:

- periodic dose rate checks are made and documented during beam operations to assure that the shielding integrity is maintained
- groundwater samples are obtained at intervals defined by the BNL SBMS and periodic soil samples are taken at known beam loss locations to assure that groundwater is not contaminated and beam losses are not excessive
- periodic confirmatory air samples are obtained to verify that air emissions remain well below 0.1 mrem per year

4.5.3.1. Primary Beam

Primary beam is the ion beam that has not yet interacted with materials and which can cause a whole body dose equivalent rate of more than 50 rem/hr, up to lethal dose. The access controls systems, ACS and PASS, prevent exposure of personnel to primary beam. For direct exposure to the primary beam particles, the only distinction between protons and heavy ions concerns the total mass stopping power and quality factor. Direct exposure is an event against which the maximum level of security is provided in the primary beam areas of C-A facilities. Safeguards against these conditions are provided in accordance with the C-A criteria for monitoring and interlocking of radiation areas. These criteria are specified in Table 3.2.2.1. To simplify safety analyses, in many instances the heavy ions are treated as an independent assembly of nucleons with a beam flux equal to the particle flux times the atomic mass number.

The RF cavities located in the vicinity of the 4 o'clock Collider region produce x-rays as a result of normal operation due to conditioning and multipacktoring. This area has the highest RF hazard compared to other C-A RF areas and thus bound the potential dose to an individual. At full power, dose rates based on measurements during engineering tests of the Proof of Principal (PoP) Collider acceleration cavity and storage cavity are expected to be in the range of 25-200 rad/hr at 1 foot from the cavity[2]. The power supplies for the cavities are interlocked to the PASS system, with the capability of stand-alone running when the Collider is not in operation. Sectionalizing gates inside the Collider Tunnel prohibit access to the cavities by personnel, when the adjacent tunnel is in an access permitted state to secure the cavity area for operation. Operation of the RF cavities does not cause x-ray radiation outside the Collider shielding.

The probability of unsafe failure of the access controls system that would allow an overexposure from primary beam or RF produced x-rays is so low[3] that this hazard is not credible and further analysis is not performed.

4.5.3.2. Prompt Secondary Radiation in Areas Outside Primary Beam Shielding

In estimating the degree of radiation risk, shielding design assumes the routine and maximum operating beam for each portion of the facility. The shield is designed to mitigate the

[2] S. Musolino, Measurements of Prompt Radiation from the PoP RF Cavity Test Stand in Building 1005 Highbay, August 8, 1995. S. Musolino, Measurements of Prompt Radiation from the Storage RF Cavity Test 4 o'clock Service Building, August 8, 1995.

[3] D. Beavis, Failures in the PLC Based Radiation Safety Systems, October 31, 2000. D. Beavis, Frequency of Interlock Testing, November 6, 2000. D. Beavis, Estimation of Time to Loss of Protection-The D-Downstream Gate, November 13, 2000.

greatest radiation hazards, which are unpolarized protons. Thus, the shield is more than adequate for protection against polarized proton or heavy ion loss because their intensity and/or individual nucleon energies are much less by comparison.

Radiation levels from routine loss of flux have been estimated for locations around the C-A complex using Monte Carlo codes or simple analytical formulas by Sullivan or Tesch. The Sullivan formulas are summarized below. Monte Carlo codes approach the solution as a succession of individual processes rather than in terms of global physical quantities. Making a mathematical experiment that is equivalent to the real physical situation simulates the cascade. Particles in the cascade are tracked from interaction to interaction. The events may be, for example, elastic or Coulomb scattering events, inelastic nuclear events in which any variety of secondary particle may be produced, absorption followed by decay, etc. The processes and particle production are randomly selected using appropriate probability distributions, which are either known or well approximated. At any point in the Monte Carlo simulation, any required macroscopic physical quantity may be scored (i.e., energy, fluence, absorbed dose, stars, etc.). When a sufficient history of events has been obtained, the expected value of each parameter may be obtained to the required statistical accuracy. For many areas, which have been studied extensively with beam faulted in a controlled fashion, results are reported directly.

For high energy particles, 1 GeV or greater, the following analytical formulas may be used for transverse shielding[4]:

$$H = 1.8 \times 10^{-5}\, S_P\, E_0^{0.76}\, e^{-\Sigma\zeta} / (R^2\, (\theta + 35/\sqrt{E_o})^2)$$

[4] A. H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, Ashford, Kent, England, 1992. Section 2.1.

for a point source, and

$$H = 2.7 \times 10^{-5}\, S_L\, E_0^{0.76}\, e^{-\Sigma(\zeta/0.94)} / (R\,(\theta + 35/\sqrt{E_o})^2)$$

for a line source.

In these equations, the symbols mean:

H = lateral dose equivalent, mrem

E_0 = primary proton energy, GeV

S_P = number of protons lost at a point, p

S_L = number of protons lost per unit length, p/m

$\zeta = d/\lambda$

d= shield thickness, g/cm^2

λ = high energy attenuation mean free path for shield material, g/cm^2 (Table 1.3 of Sullivan text[5])

R = transverse distance from beam loss to dose point, m

θ= angle from loss to dose point, degrees (90˚ is assumed based upon facility experience during fault studies)

For high energy particles, less than 1 GeV, the following analytical formulas may be used for transverse shielding[6]:

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[5] Iron is transparent to low energy neutrons and a value of 200 g/cm is used for computations involving a pure iron shield.

[6] A. H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, Ashford, Kent, England, 1992. Section 2.2.

$$H = 2 \times 10^{-5}\, S_P\, E_0^{0.76}\, e^{-\Sigma\eta}\, (1 - e^{-m}) / (R^2\, (\theta + 40/\sqrt{E_o})^2)$$

for a point source, and

$$H = 3 \times 10^{-5}\, S_L\, E_0^{0.76}\, e^{-\Sigma(\eta/0.94)}\, (1 - e^{-m}) / (R\, (\theta + 40/\sqrt{E_o})^2)$$

for a line source.

In these equations, the symbols mean:

H = lateral dose equivalent, mrem

E_0 = primary proton energy, GeV

S_P = number of protons lost at a point, p

S_L = number of protons lost per unit length, p/m

$\eta = d/(\lambda(1 - 0.8\, e^{-k}))$, where $k = 3\, E_0$ (correction for variation of high energy λ at < 1 GeV)

d= shield thickness, g/cm^2

λ = high energy attenuation mean free path for shield material, g/cm^2 (Table 1.3 of Sullivan text)

$m = 3.6\, E_0^{1.6}$ (exponent used in the $(1 - e^{-m})$ term, which corrects for the fact that, when < 1 GeV, some of the incident protons will range out in the target material from ionization events before experiencing an inelastic interaction)

R = transverse distance from beam loss to dose point, m

θ= angle from loss to dose point, degrees (90˚ is assumed based upon facility experience during fault studies)

Linac

For the Linac, the source term is a continuous proton loss during operation of 0.1% of the total beam uniformly distributed as a line source from 10 MeV to 200 MeV along the Linac centerline. The ASE Safety Limit for protons is 9 x 10^{17} Gev-nucleons/h or 1.25 x 10^{15} protons/s at 200 MeV. The present ion source configuration limits the actual Linac output to 33 to 35 mA per pulse with a ~500 μsec pulse width and a ~6 Hz beam repetition rate (6.4 x 10^{14} protons/s). The distance involved is ~135 meters so there may be a line source of 4.7 x 10^{9} protons/m/s with the 0.1% loss rate. The earth fill over the 200 MeV proton transfer line to the Booster, the LtB, is 5.4 m, with a transverse rise over run of 1 to 3 for the berm. Thus, the shield thickness at ground level is 16.2 m. The Linac enclosure itself provides 0.61 m of concrete thickness overhead and on the sides at the 200 MeV end. At the low energy end, 10 MeV, the thickness of the overlying earth is 3 m, and the wall and roof of the Linac enclosure is 0.52 m. The earth shield and concrete enclosure thickness increases as proton energy increases along the length of the Linac. At the end of the Linac tunnel, the 200 MeV proton beam splits to provide a maximum allowable flux of 1 x 10^{14} protons/s to Booster or AGS with the remaining flux transported to BLIP.

In addition to the Linac to Booster line (LtB) the Linac may inject directly into the AGS through transport along the High Energy Beam Tunnel (HEBT). This path is currently not available but is included in the discussion because it was used in the past and may be used again in the future. The earth shield over HEBT is 3 m thick with a transverse rise over run of 1 to 2, thus the shield thickness at ground level is 6 m. The area outside the HEBT is a locked and fenced enclosure, posted as a Radiation Area during Linac running. This protects personnel from a potential beam fault dose equivalent rate of about 20 mrem/hr.

The penetrations in the Linac include the tank 1 gate or tunnel entrance, many 40 cm transmission line holes, many 60 cm vacuum lines, many 60 cm cable trays, many 15 cm cable sleeves, and two bricked-up 1.8 m x 2.4 m access ports for equipment. The transmission line, cable trays, cable sleeves and vacuum penetrations do not give direct line of sight to the tanks, which contain the beam. The walkways in Building 930 along side the Linac are posted to control exposure to radiation.

The penetrations in HEBT include a plug door, many 15 cm cable sleeves, two 60 cm cable trays, one 30 cm cable opening, the LtB - Booster penetration, the TtB – Booster penetration, the AGS - HEBT door and labyrinth, a 60 cm x 120 cm airshaft, and two 7 cm cable penetrations. The cable penetrations and the airshaft do not give direct line of sight to the beam line.

The maximum credible unplanned loss is complete loss of the beam at any single point at the maximum energy for a short period. This is termed a "fault" condition throughout the text of this report. In appropriate areas, fault levels are detectable by radiation monitors essentially instantaneously, and if interlocked, the beam will shut down within a maximum of 9 seconds[7]. For areas where a fault may produce more than 20 mrem per fault, a system of access controls such as barriers and locked fences are used and the area is upgraded to one of several types of radiation controlled areas as defined in the Table 3.2.2.1.

[7] G. Bennett to D. Beavis, RSC Chairman, "Chipmunk Response Time," BNL Memorandum, October 9, 1991.

Table 4.5.3.a Summary of Routine and Faulted Beam Loss and Radiation Levels for Linac (200 MeV Protons)

Shield Type or Loss Point (2 m air assumed in addition to the shielding)	Area of Interest	Routine Dose Equivalent Rate (0.1% loss rate or 4.7×10^9 p/s-m) mrem/h	Fault Dose Equivalent[8] per Linac Pulse (6.4×10^{14} p/s; ~6 Hz) mrem/pulse (mrem/h)
Calculation:			
0.6 m concrete, 5.4 m earth	Linac Tunnel Top	1.1×10^{-7}	2×10^{-7} (0.005)
0.6 m concrete, 3 m earth	HEBT Top	5.4×10^{-4}	8.3×10^{-4} (20)
0.6 m concrete, 6 m earth	HEBT Side	1.4×10^{-8}	2.5×10^{-8} (0.001)
1.2 m concrete, 3.3 m earth	Linac Equipment Bay	1.2×10^{-5}	2×10^{-5} (0.5)
Fault Studies[9]			
Outside on Berm:			
Beam at HEBT Stops	HEBT Top	-	1.3×10^{-3} (30)
Beam at HEBT Stops	Blip Pump House Gate	-	2.7×10^{-3} (60)
Beam at HEBT Stops	In BLIP Pump House	-	5×10^{-2} (1060)
Beam at HEBT Stops	AGS / HEBT Gate	-	2.4×10^{-1} (5180)
Inside Enclosures:			
Beam Near TtB Penetration	HTB Enclosure[10]	-	1.2×10^{-2} (260)
Beam Near LtB Penetration	Booster Enclosure	-	2.6×10^{-3} (55)
Beam Near HTB Penetration	Booster Enclosure	-	7×10^{-3} (150)

The original 750 KeV Cockcroft-Walton described by Wheeler and Moore in "Shielding of the 200 MeV Linac," AGSCD-10, was replaced by a more reliable, low maintenance 750 KeV

[8] In appropriate areas, fault levels are detectable by radiation monitors instantaneously, and if interlocked, the beam will shut down within 9 seconds. It is estimated that 54 full energy beam spills may occur within this 9-second interval at a design repetition rate of 6 Hz. For areas where a fault may produce more than 20 mrem per fault, a system of access controls such as barriers and locked fences are used and the area is upgraded to one of the several types of radiation controlled areas as defined in the BNL Radiation Control Manual.
[9] D. Beavis, Summary of Linac Fault Studies 1 – 3, HTB Safety Analysis Report, Appendix 7.7 (September 1991).
[10] Small area source that is less than 1000 cm^3.

Radio Frequency Quadrupole (RFQ) in December 1988. This preinjector is equipped with a rotationally symmetric magnetron source, fast beam diagnostics, and a fast beam chopper, which removes undesirable beam between Booster bunches that are otherwise dumped in the Booster Ring. The fast beam chopper removes H^- particles at 750 KeV, particles that would otherwise be lost at Booster energies.

The 35 KeV transport line is 1.2 m long and it leads into the RFQ. The RFQ is 1.6 m long and experience indicates 85% transmission of the beam at the exit of the RFQ. The output of the RFQ is ~ 80 mA with a design output up to 100 mA. The RFQ currently operates at a ~6 Hz repetition rate (design of 10 Hz), and the beam pulse width is variable depending upon the needs of the AGS (~0.5 ms). From the exit of the RFQ, the beam is transported to the Linac entrance with loss occurring in the aperture of the first beam buncher at an energy of 750 KeV. Eighty to 85% of the beam at the Linac entrance is captured and accelerated to 200 MeV. The current configuration allows the Linac to operate with an output pulse up to 33 to 35 mA (6.4×10^{14} p/s), although the capability is there to reach higher currents in the future, about 50 mA ($\sim 10^{15}$ p/s), if the ion source is upgraded.

Based on the above performance characteristics, about 8.5×10^{13} p/s are lost in the accelerating cavities of the Linac. Most of this loss is in the first cavity, which accelerates protons to 10 MeV. The lost protons stop on the copper surfaces of the drift tubes and produce x-rays and small amounts of low energy neutrons.

Loss of protons with energies above 50 MeV in the Linac, LtB or HEBT regions produces neutrons that may reach nearby facilities. The earth shield in the Linac area rises proportionately with proton energy, up to 5.4 m when the protons reach 200 MeV. Following the Linac accelerating cavities is the LtB line that is located in the first 15 m of HEBT. Linac beam may be transported into the Booster or directly into the AGS through the full HEBT line, bypassing the Booster. Shielding over the HEBT transport line is 3 m earth and 0.6 m concrete. The mechanisms of beam loss in the Linac, LtB or HEBT are two kinds: 1) loss of longitudinal stability and 2) failure of the magnet system. These failures may give rise to total beam loss that is normally detected after several lost pulses and corrected by the operators. Transient phenomena may give rise to a continuous low-level loss of beam. While a 0.1% uniformly distributed loss is the ideal condition for the Linac, significantly greater losses are acceptable based on the actual thickness of the HEBT shielding and the proximity of other facilities around the Linac.

The limiting continuous loss in HEBT is about 2%. This is based on 25 mrem per year to personnel in the BLIP Facility, which is closest to the HEBT line, and which is occupied about 1000 hours per year. The HEBT line was originally used for direct injection of protons from Linac to AGS. Because the Linac currently injects into the Booster, the HEBT line is only used for test beams for a fraction of the time when the Linac operates. Assuming a distributed loss over HEBT line, a 36 m line source, a flux of 1 x 10^{14} protons/s to Booster or AGS, a lateral distance between BLIP and HEBT of 15 m, and loss distributed in time over 1000 hours; the line source equation indicates a maximum allowable loss rate of 5.5 x 10^{10} p/s-m during 1000 hours of operation. This is equivalent to a 2% beam loss continuously during the proton running period. A similar analysis was made for continuous loss in the LtB.

Fault studies (see Table 4.5.3.a) indicate that a point loss calculation for total beam loss in HEBT overestimates the measured dose equivalent rate outside the shield on the top of HEBT. This may be due to spreading out of the beam during an actual loss, which does not agree with point source geometry used in the calculation, or may be due to not accounting for shielding offered by magnets and beam components. In general, point source calculations are considered bounding, upper estimates since they are difficult, if not impossible, to achieve.

Within the BLIP Pump House are cooling lines containing water activated by primary beam losses in the HEBT beam stop. Very short-lived dissolved radioactive gases are in the water, which give rise to a photon flux in the Pump House that adds to the dose equivalent from neutrons arising from primary beam losses.

The polarized proton beam originates as a negatively ionized vertically polarized hydrogen beam from a polarized ion source. These H- ions are injected into the Linac RFQ. The beam is transported through the Low Energy Beam Transport line (LEBT) into the Linac where it is accelerated to 200 MeV. The beam accelerates from the RFQ with a maximum of a few TP per second reaching 200 MeV. This flux is an order of magnitude less than unpolarized protons.

An x-ray hazard along the length of the Linac rf tanks exists whenever a spark occurs. Exposure rates near the tanks at a level of 1 to 5 R/h have been observed during normal operations. This area is on restricted access during maintenance periods and requires training and a self-reading dosimeter for entry. Even though entry through the Linac Tank 1 gate ensures proton beam is interlocked off, the rf may be reset from inside the gate for testing purposes. In addition to training in the hazards associated with this area, a series of fluorescent lights along the tanks warns personnel that rf radiation is present.

Tandem and TtB

By its very nature, the TVDG facility has a complex and varied capability for producing radiation depending on the type of ion being accelerated. Energies of Tandem accelerated ions are proportional to the charge state achieved by the ions when they undergo stripping within the accelerator tank. Because lighter ions can be stripped to charge states comparable to their atomic numbers, they can achieve a relatively high energy per nucleon and as such are capable of producing appreciable numbers of fast neutrons and associated gamma-rays when they strike a target. Heavier ions cannot be stripped to charge states comparable to their atomic number so they can only attain a relatively low energy per nucleon. Such particles do not produce nuclear reactions when striking a target, and thus do not produce an appreciable radiation field. As a result of this diverse capability for producing radiation, a very diverse access controls system is in place. Studies have shown that adequate controls are in place.[11]

The TtB shield and the TtB beam current monitoring device are designed to mitigate the greatest radiation hazards, which exist when running with low-mass ions. The shield alone is more than adequate for protection against high-mass heavy-ion losses because heavy-ion beam intensity and/or individual nucleon energies are much less by comparison.

After examining the experimental needs at RHIC, it was determined that the annual, total number of deuterons would need to be about 7×10^{17}. This accounts for normal beam losses and deuteron beam tuning in Tandem, TtB, Booster, AGS and AtR.

When the TtB line is delivering beam to downstream users, a 10% beam loss has been observed. No specific points of chronic loss have been identified, and the distribution of these losses is not known. When the TtB line itself is being tuned, beam loss is inherent in the tuning process as wire chambers and Faraday cups are inserted at various places in the line. Adding these losses gives a total loss estimate at a single point of about 2×10^{16} deuterons per year. The

[11] J. Benjamin, C. Carlson, J. Throwe and F. Zafonte, Building 901A Shielding Effectiveness Studies, 7/92 and 4/94, Tandem Van de Graaff Facility, August 1994. This is Appendix XI of the TVDG SAD dated June 1995.

maximum incremental loss at a single point was estimated to be about 4.5×10^{13} deuterons in one hour.

The normal running current in the TVDG accelerator room was initially planned to be 67 nA of deuteron beam at 12 MeV. The normal terminal voltage was planned to be 6 MV. For a full-energy beam fault, radiation levels from deuterons could fault to about 50 rem/h at one foot at 0^o from a 30 MeV deuteron beam that would result from a voltage fault of 15 MV. For a full-intensity beam fault, the radiation level could fault to a few hundred rem/h at 1 foot at 0^o if the current is intentionally tuned to maximum 10 μA. Thus, dual redundant interlocks are required in the TVDG accelerator room for deuteron operations. It is noted these fault conditions require two events: an intensity or voltage fault and stopping the beam at a single point. These radiation levels are summarized below in Table 4.5.3.b.

Table 4.5.3.b Calculated Radiation Levels in the TVDG Accelerator Room and the TtB (Deuterons)

Loss Description	**Deuteron Current**	**Terminal Voltage**	**Instantaneous Dose Equivalent at 1 foot at 0^o, rem/h**
TVDG Normal Beam, Point Loss (single fault)	67 nA	6 MV	1.5
TVDG Full Energy Beam, Point Loss (double fault*)	67 nA	15 MV	50
TVDG Full Current Beam, Point Loss (double fault*)	10,000 nA	6 MV	230
TtB Normal Beam, Anticipated Beam Loss (routine loss)	6.7 nA or 10% in transit to RHIC ($4.5x10^{13}$ deuterons for one hour at a point)	6 MV 6 MV	0.15 0.04
TtB Normal Beam, Point Loss (single fault)	67 nA	6 MV	1.5
TtB Full Current Beam, Point Loss (double fault)	200 nA	6 MV	4.5

* Double fault - intensity or voltage fault coupled with stopping the beam at a single point.

The actual parameter limits for the FY 03 d-Au run as authorized by the RSC at RHIC were eventually increased to 18 MeV deuterons[12], a 200 nA interlock and an alarm at 80 nA. These conditions are well bounded by the double fault condition analyzed above.

[12] K. Yip, Increased Neutron Dose Due to Increased Deuteron Energy in the TTB Line, December 15, 2002.

Booster

Among the three operating modes of the Booster, which are high flux unpolarized proton beam, polarized proton beam, and heavy ion beams, the high flux unpolarized proton operation represents the greatest ionizing radiation hazard. With the exception of the shielding over the first dipole following the stripper for heavy ions, all calculations for shielding and activation are based on fluxes associated with unpolarized protons.

Table 4.5.3.c Summary of Booster Beam Flux and Beam Loss

Parameter	Unpolarized A = 1	Polarized A = 1	Sulfur A = 32	Gold A = 197
Beam Flux (sec^{-1})	1×10^{14}	1.5×10^{12}	1.5×10^{10} ions	3.2×10^{9} ions
Injection Loss (sec^{-1})	1×10^{13}	3×10^{11}	3×10^{8} ions	6×10^{7} ions
Injection Energy (MeV/nucleon)	200	200	4.688	1.066
Acceleration Losses (sec^{-1})	6×10^{11}	1.5×10^{10}	1.5×10^{8} ions	3.2×10^{7} ions
Extraction Losses (sec^{-1})	2×10^{13}	1.5×10^{10}	1.5×10^{8} ions	3.2×10^{7} ions
Stripper Losses	NA	NA	1.5×10^{9} ions	1.6×10^{9} ions
Extraction Energy (GeV/nucleon)	1.5 to 2.2	1.5 to 2.2	0.967	0.35
Maximum Credible Loss at Extraction Energy	1×10^{14}	1.5×10^{12}	1.5×10^{10} ions	3.2×10^{9} ions

For a planned beam loss, the assumption is 50% of the loss occurs at a single point such as the dump/catcher and the remainder uniformly distributes around the Booster Ring. For extraction loss, 80% of the loss is on the septum and 20% is on the first dipole downstream. The maximum credible unplanned loss is complete loss of the beam at any single point at the maximum energy for a short period of time. Generally, the only distinction between protons and heavy ions concerns the total mass stopping power from direct exposure to the primary beam particles. This is an event against which the maximum level of security is provided in the primary beam areas of the Booster. In all other instances, the heavy ions are treated as an independent assembly of nucleons with a beam flux equal to the particle flux times the atomic mass number. Safeguards against all loss conditions are provided in accordance with the C-A criteria for monitoring and interlocking of radiation areas.

The shielding of the tunnel enclosure and the interfaces to the 200 MeV proton Linac and the AGS have been analyzed by Gollon[13], Casey[14] and Lessard[15]. Sufficient shielding is provided to ensure that radiation levels in all areas for normal operating conditions meet BNL and DOE criteria. Fault conditions were analyzed to ensure that unacceptable radiation levels are controlled. The types of warning/control systems are consistent with the existing C-A area classifications.

A summary of the results is presented in the following tables with details given in the following text. These computed values are upper limits because it is not possible to lose the

[13] P. J. Gollon, Booster Tunnel Shield Calculation, Booster Technical Note #66, October 24, 1986, in AGS Booster Project Preliminary Safety Analysis Report, Appendix 7.1, Brookhaven National Laboratory, Upton New York, 11973, December 1, 1987.
[14] W. R. Casey, Additional Booster Shielding Calculations, Booster Technical Note #93. September 28, 1987 in AGS Booster Project Preliminary Safety Analysis Report, Appendix 7.2, Brookhaven National Laboratory, Upton New York, 11973, December 1, 1987.
[15] E. T. Lessard, Booster Shield Wall/Door Analysis, March 30, 1989.

beam at a single point. It is noted that the current Booster design limits the extraction energy to ~2 GeV, however 2.2.GeV was conservatively used to bound the computed doses.

Table 4.5.3.d Summary of Booster Flux Loss and Radiation Level Summary

Loss Flux Type (particles/s)	Area of Interest	Nucleon Energy	Routine Peak Dose Rate (mrem/h)	Peak Fault Dose Rate[16] (mrem/h) (Maximum Flux)
Injection (1×10^{13})	Booster Tunnel Top	200 MeV	0.0003	30 (4×10^{14})
Injection (1×10^{13})	Booster Tunnel Side	200 MeV	0.00006	0.6 (4×10^{14})
Acceleration (6×10^{11})	Booster Tunnel Top	700 MeV	0.2	2500 (1×10^{14})
Acceleration (6×10^{11})	Booster Tunnel Side	700 MeV	0.04	150 (1×10^{14})
Fault (1×10^{14})	Booster Tunnel Top	2.2 GeV	NA	6800
Fault (1×10^{14})	Booster Tunnel Side	2.2 GeV	NA	450
Extraction (2×10^{13})	B914 Roof Over Septum	2.2 GeV	300	1650 (1×10^{14})
Extraction (1×10^{14})	Remaining B914 Roof	2.2 GeV	3	205,000
Studies (1.5×10^{13})	Booster Tunnel Over Dump	2.2 GeV	20	130 (1×10^{14})
Studies (1.5×10^{13})	Fence Near Dump	2.2 GeV	0.3	2 (1×10^{14})
Fault (1×10^{14})	AGS from Booster	2.2 GeV	NA	750
Fault (1×10^{14})	AGS Labyrinth. Door from Booster	2.2 GeV	NA	1350
Fault (4×10^{14})	Booster from Linac	200 MeV	NA	240
Fault (1.3×10^{13})	Booster from AGS	28 GeV	NA	1400
Fault (1.3×10^{13})	Booster Labyrinth. Door from AGS	28 GeV	NA	2500
Extraction (1.6×10^{9}) - Gold	B914 Roof Over Stripper	1.066 GeV	5	10 (3.2×10^{9})
Extraction (6×10^{11})	B914 Plug Door	2.2 GeV	2.7	680 (1×10^{14})
Extraction (6×10^{11})	B914 Man-Gate	2.2 GeV	0.7	160 (1×10^{14})
Extraction (6×10^{11})	B914 North Entrance	2.2 GeV	0.3	70 (1×10^{14})

[16] Fault levels are detectable by radiation monitors after one pulse. When the fault is detected and stopped after one second, the accidental dose to an individual in unfenced areas is well below the design guideline of 20 mrem.

Injection losses are estimated at 10% ($1x10^{13}$ p/s) at 200 MeV. Assuming that all of these losses occur at a single point, the dump/catcher, a peak radiation level of 0.3 µrem/h is produced at the top of the berm and less than 0.06 µrem/h horizontally. The dump/catcher is shielded internally with one meter of heavy concrete equivalent and externally with 5.5 m of sand. The Booster Ring is shielded less, 4.6 m of sand vertically and 6.1 m horizontally, when compared to the dump area and the fault flux for 200 MeV protons $4x10^{14}$ p/s. Therefore, away from the dump area, a fault level of 30 mrem/h at the berm top and 0.6 mrem/h at the berm side is possible with injection energy protons for a short period of time.

Planned losses during acceleration are 1% or less and occur with an average energy of 700 MeV. Assuming all of these are lost at a point, which is the dump/catcher, peak radiation levels are 0.2 mrem/h at the top of the berm and 0.04 mrem/h at the side of the berm. If a point loss during acceleration occurred at full beam flux, 1×10^{14} p/s, the berm top would peak at 2500 mrem/h, and the berm side at 150 mrem/h. Fault losses are typically not at a point and distribute over 10 m or more at these momenta. Radiation levels decrease by a factor of two for a loss spread over 10 m, and by a factor of 30 if losses are spread uniformly around the entire Booster Ring.

Faults at 100% of the beam at 2.2 GeV at a point for a short period of time result in up to 6.8 rem/h at the berm top and 450 mrem/h horizontally. Due to these potential levels, the berm is posted in accordance with the requirements of the BNL Radiological Control Manual and is enclosed by a fence. Access is limited to authorized individuals only.

Losses at extraction are about 30% and occur at an energy of 2.2 GeV. All of these losses are assumed to occur on the extraction septum (80%) and the first dipole magnet (20%) following the septum inside Building 914. Building 914 was constructed from the decommissioned 50 MeV Linac and has a structural limitation of 1.8 m of soil overhead. Sixty centimeters of iron rising to 2.3 m in the forward direction where space permits reduces the routine exterior radiation level on top Building 914 to about 300 mrem/h, which occurs over a 40 m^2 area. Most of the remaining Building 914 roof is about 3 mrem/h for routine extraction loss conditions.

Since the internal iron shield does not fully enclose the transfer line between the Booster and the AGS, momentary peak levels of 57 mrem/s are possible under full fault conditions at 7.5 Hz or $1x10^{14}$ p/s. For this reason, the roof area above Building 914 is fenced and secured as a Class III area with possible faults into Class II, and the access gate configured with a hard-wired switchgear type relay that interlocks the beam. In addition, redundant radiation monitors are used in this region to interlock the beam and limit the duration of the fault. Based on experience at the AGS, fault levels are detectable by radiation monitors after one pulse. If $1x10^{14}$ p/s stop in the region not enclosed by iron, about 57 mrem in one second occurs within the fenced-in region on top of Building 914. If the fault is detected and stopped after one second, the accidental dose to a person would be much less than the design guideline of 20 mrem since the nearest uncontrolled area is 50 feet away.

The first dipole past the heavy ion stripper, which is in the transfer line between the Booster and AGS, requires overlying shielding. Projected energy losses are $1x10^{11}$ GeV/s for Au ions. Poorly stripped ions are swept out at the first dipole after the stripper. A local iron shield 36 cm thick is installed to reduce exterior levels to less than 5 mrem/h on the roof of Building 914. Fault levels are 10 mrem/h.

During Booster studies, the beam dump can receive the full Booster beam. Studies are normally conducted at a peak flux of 1.5×10^{13} p/s at 1.5 GeV but 2.2 GeV is assumed, and studies do not occur more than about 500 h/y. The thickness of the steel dump and the iron shield surrounding it contribute an additional equivalence of 1 m of heavy concrete. The sand berm over the dump is 5.5 m thick and this thickness extends 15 m horizontally from the dump. The external radiation levels over the top of the berm are 20 mrem for one hour of studies and about 0.3 mrem in one hour at the berm fence. Fault levels are about six times these planned levels.

At Building 914, routine occupancy near the inhabitable side of the shield wall or man-gate opening would not occur. Because of possible fault levels of 300 mrem/h for a short period, the inhabitable portion of Building 914 is designated as a Radiation Area, and an alarmed/interlocked radiation monitor is installed. The entrance to Building 914 is 27 m from the shield wall and man-gate. The routine dose rate at the North Entrance is less than 0.01 mrem/h. Routinely, the highest levels are near the shield wall and man-gate entrance and they are 0.1 mrem/h. These estimates are based on a septum that is unshielded along its side and a 30% flux loss. In fact, the septum has a light-concrete photon shield along side it in order to reduce the residual radiation when passing by or working nearby that would also act as a shield during operations.

At least 2.4 m of concrete shielding is placed at the interface between the Booster tunnel and the 200 MeV high-energy beam transport (HEBT) tunnel of the Linac. The radiation at the Booster side of the interface shield is less than 0.4 mrem/h assuming a planned loss of less than 1% in the Linac HEBT. A fault loss of the maximum Linac beam (~35 mA) at a point in the HEBT line near the interface to the Booster results in 240 mrem/h in the Booster tunnel. Such losses would be detected by the Linac radiation monitoring system, which would automatically turn the beam off.

Multiple redundant lockout of bending magnets in the Linac/Booster transfer line inhibit the direct transfer of Linac beam into the Booster tunnel, unless the Booster tunnel is clear of personnel and secure for normal operation.

Certain special areas, where the side shield is thinner than usual because of space restrictions, such as in the interface of the Booster with the Linac building and Building 914, have concrete or steel inserts in order to assure at least 6 m of equivalent earth. This keeps levels under normal conditions to less than 0.3 mrem/h.

The side shielding at the interface between the Booster and the AGS, which is the equivalent of 6 m of earth side shielding, is designed so that the two machines can operate independently of each other while the other tunnel is opened for maintenance. This criterion is necessary because the Booster may operate with one type of particle beam (e.g. heavy ions for NASA experiments at NSRL), while the AGS is engaged in physics operation with direct injection of another particle beam. Under these conditions, independent access is required. There is a labyrinth passage, joining the AGS and the Booster Rings, with High Hazard Radiation Area security doors at each end. 0pening these doors crashes the machines. During Booster operation while the AGS tunnel is open, interlocks on the beam transfer dipole in the Booster extraction channel inhibit the transfer of primary beam to the AGS. The worst credible accident, loss of the Booster beam at the Building 914 wall near the AGS, causes levels in the AGS tunnel to rise to 750 mrem/h for 1 to 2 seconds. The reverse case is operation of the AGS while the Booster tunnel is open for maintenance. The reverse case, which had been possible in the past cannot occur under the current configuration, is included should it be used in the future. For operation of the AGS at a maximum beam flux of 2 x 10^{13} protons per pulse at 1.5-second repetition rate, the worst case of total beam loss causes 1400 mrem/h in Building 914 for approximately 1 to 2 seconds. Radiation monitors interlocked to each machines operation are provided.

Transmission from losses in the AGS through the AGS-Booster labyrinth is measured at 4×10^{-5}. Calculations indicate that transmission through the labyrinth is from 8×10^{-6} to 4×10^{-7} for a loss at the mouth of the labyrinth. The measured transmission cannot be directly compared to calculations since losses occurred near the mouth and along the sidewall of the labyrinth in the AGS Ring. Using the measured transmission, the worst-case level is 2500 mrem/h. The reverse, which is the worst-case level at the AGS door to the labyrinth from a loss in the Booster, is 1000 mrem/h assuming that the 4×10^{-5} transmission value applies.

NASA Space Radiation Laboratory (NSRL)

A summary of the routine maximum and faulted beam assumptions for NSRL safety analyses are shown in Table 4.5.3.e:

Table 4.5.3.e Summary of Routine, Maximum and Faulted Beam Assumptions for NSRL

Quantity	**Maximum Value**
Annual Energy Flux from Booster SEB	10^{17} GeV in one year
Hourly Energy Flux from Booster SEB	$6x10^{14}$ GeV in one hour
Annual Energy Flux on the NSRL Beam Stop	$3x10^{16}$ GeV in one year
Hourly Energy Flux on the NSRL Beam Stop	$6x10^{14}$ GeV in one hour
Annual Energy Flux on NSRL Targets (0.25 nuclear interaction lengths)	$3x10^{16}$ GeV in one year
Hourly Energy Flux on NSRL Targets (1.0 nuclear interaction length)	$6x10^{14}$ GeV in one hour
Maximum, Single Event, Non-routine Point Loss at any Location[17]	$6.75x10^{15}$ GeV

The prompt radiation at the edge of the berm above the target in the Target Room, which is the point of minimum shield thickness, was computed using the Tesch formula[18] for 3.07 GeV protons. This dose was found to be 2.42×10^{-17} rem per proton. Table 4.5.3.e prescribes a maximum hourly limit of beam interacting on target to be 6×10^{14} GeV, which would result in 4.73 mrem per hour. Averaged over a year, the hourly dose is much less. For a "thick target" the average GeV per hour is 2×10^{13} versus the 6×10^{14} considered above, for a reduction factor of 0.033, or an average dose rate of 0.16 mrem/hr.

[17] The maximum, single-event, non-routine point loss is $1.5x10^{14}$ 5-GeV nucleons/sec for 9 seconds. Nine-seconds is the assumed response time of fixed-area radiation monitors to interlock the beam. Thus, a single-event, high-energy nucleon loss of $6.75x10^{15}$ GeV is the maximum fault assumption for any location at NSRL. It is noted in BNL Memorandum, J. Geller to D. Beavis, RSC Chair, "Time to Chipmunk Interlock for Large Radiation Faults," March 2, 1999 that tests of the internal chipmunk circuitry yield an absolute minimum response time of 0.65 seconds. Nine seconds is taken to include the response time of the external circuitry that includes relays and critical devices.

[18] K. Tesch and H. Dinter, Radiation Protection Dosimetry, Vol. 15 No. 2 pp. 89-107 (1986).

The dose on the berm slope shown next to the beam dump was compared to the dose at 90° with respect to the target on the top berm using the CASIM program for high-energy particle ***cas***cade-***sim***ulations.[19] The result was that the dose on the slope is less than at the berm top. Thus, the hourly dose rates at the top of the berm are bounding, even for the situation where no target is in place.

Upstream of the Target Room the shielding consists of 15 feet of earth. At the edge of the berm here, the Tesch formula gives 4.52×10^{-17} rem per proton. Assuming a 5% inadvertent loss of the maximum hourly limit (3×10^{13} GeV) gives 0.44 mrem/hr. The average hourly dose rate corresponding to a chronic 5% inadvertent loss is a factor of 0.033 less, which is a dose rate of 0.015 mrem/hr. The assumption of a hypothetical 5% loss just before the target is based on experience with the final focusing magnet in a beam line at AGS; however, it is noted that operators monitor losses and are required to reduce beam losses to ALARA levels.

The prompt radiation at the nearest point in the Target Room is estimated by evaluation of the labyrinth connecting the Target Room with the Support Building 958 which is occupied with experimenters during operations of NSRL. The estimate was made using the MCNPX code. The dose at door of the support building assuming 3.07 GeV protons incident on a 12 cm plastic target, which is 0.16 interaction length, is 10^{-18} rem per proton. The maximum hourly dose is obtained by assuming 6×10^{14} GeV on a one interaction length target. It is assumed that neutrons dominate the dose at the support building labyrinth-door. The re-entrant dump design supports this assumption. The resultant maximum dose rate is 0.84 mrem per hour. The average hourly rate assumes a 0.25 interaction length target. Combining this with the average 2×10^{13} GeV per hour gives 0.01 mrem per hour.

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[19] The CASIM code overestimates the dose in the forward direction when compared to the actual condition estimated by improved codes such as MCNPX at the GeV energy scale.

Alternating Gradient Synchrotron (AGS)

In estimating the degree of radiation risk, assumptions about the beam flux and the beam loss are made. They are based on the design of the AGS facility and are indicated in Table 4.5.3.f. The fundamental assumption is that the shield is designed to mitigate the greatest radiation hazard. Thus, a shield designed to specifications for unpolarized proton loss is more than adequate for protection against polarized proton loss or heavy ion loss since their flux and/or individual nucleon energies are much less by comparison. The AGS has been analyzed assuming a maximum beam flux of 1 x 10^{14} unpolarized protons per second.

Table 4.5.3.f Summary of Planned Beam Loss in the AGS Ring

Location and Beam Energy	Spot Loss Near Thick Shield (% of beam flux)	Spot Loss Near Thin Shield (% of beam flux)	Distributed Loss (% of beam flux)
Injection Losses (1.5 – 2.2 GeV)	8	1	1
Transition Losses (7 GeV)	0.9	0.05	0.05
Extraction Losses (27.5 GeV)	0.9	0.05	0.05
Studies Losses (10 GeV)	4.9	0.05	0.05

The above Table assumes that protons are injected into the AGS Ring through the Booster. Direct injection into the AGS is a possibility by transporting beam from the Linac through HEBT. This ability is not possible without modifications but is included in the discussion should it be used in the future. In this mode of operation, injection losses are approximately 60% at 200 MeV based on the measurements reported during the 1986 Slow Extracted Beam run. This lost energy flux at injection, $1.2x10^{13}$ GeV/s, is the well below the 8% at 1.5 to 2.2 GeV using the Booster. Thus, the injection losses assuming the Booster is operating bound the dose consequences for either mode of operation.

Unpolarized proton losses are more explicitly stated in Table 4.5.3.g, and the location of the loss is indicated by correlating the loss with the amount of overlying shielding. Additional shielding by magnets of 0.42 m of iron pole tip is assumed to attenuate radiations rising in the vertical direction towards the top of the shield. Experience shows that when viewed indirectly through measurements at the outer surface of a thick shield, a point loss in the AGS Ring has a characteristic source length of 16 m for the most localized beam loss.

Table 4.5.3.g Proton Beam Loss and Location in the AGS Ring

Loss Type	Protons Lost per Year	Protons Lost per Meter-Year	Energy (GeV)	Concrete Thickness (m)	Earth and Soilcrete Thickness (m)
Injection[a]	6.6×10^{19}	4.1×10^{18}	1.5 – 2.2	0.3	6.0
Injection[b]	8.2×10^{18}	1.0×10^{16}	1.5 – 2.2	0.3	5.7
Injection[a]	8.2×10^{18}	5.1×10^{17}	1.5 – 2.2	0.3	4.5
Transition[a]	7.4×10^{18}	4.6×10^{17}	7	0.3	6.3
Transition[b]	4.1×10^{17}	5.1×10^{14}	7	0.3	5.7
Transition[a]	4.1×10^{17}	2.5×10^{16}	7	0.3	4.5
Ejection[a]	7.4×10^{18}	4.6×10^{17}	27.5	0.3	6.3
Ejection[b]	4.1×10^{17}	5.1×10^{14}	27.5	0.3	5.7
Ejection[a]	4.1×10^{17}	2.5×10^{16}	27.5	0.3	4.5
Studies[a]	4.2×10^{19}	2.6×10^{18}	10	0.3	6.3
Studies[b]	4.1×10^{17}	5.1×10^{14}	10	0.3	5.7
Studies[a]	4.1×10^{17}	2.5×10^{16}	10	0.3	4.5

a: 16 m spot loss
b: Loss distributed around Ring, 800 m

Essentially, two types of shield exist at the AGS Ring. One is a 6 to 6.9 m thick earth and soil-cement shield which covers the major areas overlying the injection, transition, ejection and studies losses. Another is a 4.5 to 5.1 m thick earth and soil-cement shield which covers the remaining parts of the AGS Ring. The beam height is 3.3 m below the concrete roof of the AGS Ring which is used to support the over lying layers of soil and soil-cement. The specific thicknesses of top shield are listed in Table 4.5.3.h below:

Table 4.5.3.h Thickness of Top Shield

Top of Sector	**Shield (meters)**
G20 - I13	6.0
I13 - J5	5.1
J5 - K5	6.3
K5 - L10	5.1
L10 - A15	6.0
A15 - B10	6.0
B10 - D10	4.5
D15 - E20	4.5
E20 - F20	6.9

The section F20 through G20 is the AGS target building portion of the Ring, and the shield top thickness is 2.4 m heavy concrete or more, which is 4.7 m earth equivalent or more. The shield thickness for the berm top is not continuous. It is punctuated by penetrations which are: 2 escape hatches, a series of pipes varying in diameter from 20 to 60 cm, 5 fan houses, 4 labyrinths, 2 plug doors, 1 gate, 1 trench, 1 cable run, the north and south wiring tunnels, the FEB tunnel, the north conjunction area, and the target building. Additionally, a roadway crosses the berm top between D10 and D15 and near J10. The shield thickness beneath the roadway is 3 m of earth.

For a planned beam loss, the assumption is that part of the loss occurs at a single place such as the internal dump/catcher at J10, which is shielded by the thicker part of the berm, and the remainder of the loss uniformly distributes around the AGS Ring. Additionally, as viewed from the outside of a shield, a 16 m loss is assumed to occur routinely at any thin part of the Ring shield, rather than a less conservative distributed loss.

A summary of the computed dose equivalent rate results for the AGS is given below in Tables 4.5.3.i and 4.5.3.j. These estimates are overly conservative but show that adequate shielding is in place. Many of the areas have had shielding upgrades that are not reflected in the computed fault doses.

Table 4.5.3.i AGS Flux Loss and Radiation Level Summary

Shield Type	**Area of Interest**	**Operation**	**Nucleon Energy (GeV)**	**Routine Dose Equivalent Rate (mrem/h)**	**Fault Dose Equivalent per AGS Pulse[20] (mrem/pulse)**
Thin				0.5	0.02
Thick			0.3		0.001
Distributed	AGS Ring Top	Injection	1.5 – 2.2	0.002	-
Thin				0.1	0.1
Thick				0.08	0.005
Distributed	AGS Ring Top	Transition	7	0.003	-
Thin				0.5	0.4
Thick				0.3	0.02
Distributed	AGS Ring Top	Extraction	27.5	0.001	-
Thin				0.2	0.02
Thick				0.6	0.005
Distributed	AGS Ring Top	Studies	10	0.0004	-

[20] 10^{14} p/s at 0.84 Hz. In appropriate areas, fault levels are detectable by radiation monitors instantaneously, and if interlocked, the beam will shut down within 9 seconds. It is estimated that three full energy beam spills may occur with this 9-second interval at the current repletion rate of 0.42 Hz. For areas where a fault may produce more than 20 mrem per fault, a system of access controls, such as barriers and locked fences are used and the area is upgraded to one of the radiation controlled areas described in the C-A OPM, Section 9.0 series.

Table 4.5.3.j Fault Levels at AGS Ring Penetrations[21]

Area of Interest	**Fault Dose Equivalent per AGS Pulse (mrem/pulse)**
C-14 Escape Hatch	30
Booster/AGS Interface	5
Linac/AGS Interface	30
Road over AGS Berm	50
North Conjunction Area	50
Pipes (Weakest Case)	100
Fan House Ducts (Weakest Case)	500
Entrance Labyrinths (Weakest Case)	10
Plug Doors (Weakest Case)	10
AGS-Booster Trench	500
Side Wall Interface w/Target Bldg 912 (Weakest Case)	10,000

Near J-10, beginning at the onset of catching and scraping for studies, transition and extraction losses, and extending at least 15 m past the most forward point of these losses, an overlying earth shield 6.3 m thick plus 0.6 m concrete with a berm rise over run of 1 to 2 is constructed. This reduces annual dose equivalent in Buildings 919 and 921 to less than 25 mrem in one year for an individual.

If J-10 is not used, studies, transition and extraction losses occur near E-20. Beginning at the onset of these losses and extending at least 15 m past the most forward point at which these

[21] The attenuation factors are taken from the Beavis Report (D. Beavis, Ring-Me, Potential Radiation Fault Levels from Beam Faults in the AGS Ring, AGS/EP&S/ Technical Note No. 138, October 1991). The source term used by Beavis was multiplied by 3.3 for the purposes of this tabulation in order to account for the potential 10µA proton beam operations at 100% duty factor (3000 AGS pulses/h). Protection is shielding, interlocking radiation monitors, fences and access controls.

losses occur, an overlying earth shield 6.9 m thick plus 0.6 m concrete is constructed. The side of the berm has a rise over run of 1 to 2. This reduces dose equivalent in Building 911 to less than 25 mrem in one year.

At the onset of injection losses and extending at least 15 m beyond the most forward point at which these losses occur, an overlying earth shield at least 5.1 m thick plus 0.6 m concrete is constructed. The berm rise over run is 1 to 2. This reduces dose equivalent to below 25 mrem in one year for persons in Buildings 931A and 931B.

In the analysis for direct radiation, the AGS Ring shield is visualized as 25 slabs of side shield of varying thickness in order to estimate the number of emerging neutrons which contribute to dose equivalent at a distant point. The closest point in the analysis is 15 m from the base of the AGS berm, which is the approximate location of the fence. Additionally, a direct radiation component from neutrons emerging from the top of the berm is included. The furthest point used in the calculation of direct radiation exposure is 150 m since additional shielding from interposed buildings, trees and hills is not accounted for.

The shield is at least 6 m of earth-cement mixture, or soilcrete as it is sometimes called, between the major loss points and occupied areas, and at least 4.8 m of earth between the remaining loss points and unoccupied areas. Annual dose equivalent from direct radiation to workers in Building 911 is estimated to be less than 5 mrem per year. The annual dose equivalent to the nearest person from skyshine is estimated to be much less than 1 mrem. For uncontrolled areas where buildings may exist, the maximum fault dose rate within the nearest occupied building is less than 5 mrem in one hour. Actual doses as measured by TLD studies show that these computed values are very conservative.

An AGS Ring Shield Upgrade Group was formed in 1988 to define the maximum beam losses for future running and to prepare a proposal for additional radiation protection. Their work is described in a number of papers.[22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38]

The locations of interest are: 1) Buildings 911, 919, 921, 928 and 929 where they are penetrated by direct radiation from losses in sections A and J of the AGS Ring, and by distributed losses, 2) occupied and unoccupied surfaces directly above a fault condition, and 3) areas affected by skyshine.

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[22] Th. Sluyters to D. I. Lowenstein, " AGS Ring Shield Upgrade Group, BNL Memorandum, July 26, 1988.
[23] G. Bennett, "Skinny Shield Studies/Calculations," Informal Note (July 19, 1988).
[24] E. T. Lessard to AGS Ring Shield Upgrade Group, "Design Criteria," BNL Memorandum, August 9, 1988.
[25] J. W. Glenn to AGS Ring Shielding Upgrade Group, "Short Meeting on Wed. August 31," Informal Memorandum, August 31, 1988.
[26] E. T. Lessard to J. W. Glenn, "Skyshine Transfer Function, On and Off Site," BNL Memorandum, September 21, 1988.
[27] AGS Staff, Shielding of the AGS from the Conversion Program, Accelerator Department, Brookhaven National Laboratory, Upton New York, 11973, A Report Prepared for the AEC Advisory Panel on Accelerator Safety (June 15, 1966).
[28] G. Bennett, L. Blumberg, C. Distenfeld, H. Foelsche, W. Moore, T. Toohig and G. Wheeler, Shielding of the North Experimental Facility and the Slow External Beam Extension, Accelerator Department, Brook haven National Laboratory, Upton New York, 11973, A Report Prepared for the AEC Advisory Panel on Accelerator Safety (February 25, 1970).
[29] H. Foelsche, "Expected Running and Maintenance Schedule for AGS Shield Upgrade," Informal Memorandum, September 27, 1988.
[30] A. Stevens, "Comparison of CASIM Calculation with Bennett's Flip Target Experiment," Informal Memorandum, October 4, 1988.
[31] K. A. Brown to J. W. Glenn, "Beam Losses and Residual Activation in the AGS," BNL Memorandum, October 4, 1988.
[32] A. J. Stevens to J. W. Glenn, "Preliminary Estimate of Skyshine from AGS Ring," Informal Memorandum, October 10, 1988.
[33] E. T. Lessard to J. W. Glenn, "AGS Ring Shielding Upgrade Group and Goals," BNL Memorandum, November 4, 1988.
[34] K. Brown, J. W. Glenn, S. Musolino, A. Stevens, R. Thern, "AGS Shield Tests," AGS Studies Report, Number 245 (November 21, 1988).
[35] E. T. Lessard to J. W. Glenn, "AGS Shielding Upgrade Analysis," BNL Memorandum, December 8, 1988.
[36] K. Brown to J. W. Glenn, "Losses and Activation in the AGS," BNL Memorandum, December 8, 1988.
[37] E. T. Lessard to J. W. Glenn, "AGS Shielding Upgrade Analysis: Revised Loss Assumptions and Close to Shield Estimates," BNL Memorandum, January 5, 1989.
[38] H. Foelsche and E. T. Lessard to J. W. Glenn, "Specific Shield Requirements for the AGS Ring Upgrade," January 23, 1989.

The following assumptions are made: 1) full beam loss, 10 microamps operation at 100% duty factor, produces the maximum dose rate, and 2) hot spot or point losses as viewed from the outer shield surface are distributed over 16 m.

Dose to people is from neutron and gamma radiation which result from high energy particles penetrating and interacting in the outer overlying layers of the shield. The integrated number of particles emanating from each 1 m section of shield surface area was computed. The center of each small section is termed a node. Radiations are assumed to emanate semi-isotropically from each node to all points on the surface. Dose at any point on the Laboratory site was based on radiation emanating from all nodes, and based on assuming the entire shield surface dose was from neutrons. Most of this dose is from the thinnest part of the side shield which is near the top of the berm. Dose directly through the side shield, which is very thick at ground level, is a small fraction of dose from radiations which shine down from the top of the berm. In addition to dose from this radiation, the dose from high energy particles which penetrate and interact in the air column above the surface of major loss points, the skyshine dose is calculated from standard methods.[39]

For persons occupying buildings, local shielding from the structure was assumed to reduce skyshine dose. Assuming that the dosimetrically significant energy of the neutron flux resulting from skyshine at Building 911 is between 0.5 and 3 MeV[40, 41] 15 cm of concrete presented by the walls and roof reduces neutron dose by a factor of 2 to 10 (see Figures 61

[39] G. R. Stevenson and R. H. Thomas, "A Simple Procedure for the Estimation of Neutron Skyshine from Proton Accelerators," Health Phys. 46, 115-122 (1984).
[40] J. M. Zazula, D. Filges and P. Cloth, "Sky- and Groundshine Phenomena and Related Radiological Quantities Evaluated fro the Environment of a High Current Spallation Facility," Particle Accelerators 21, 29-42 (1987).
[41] C. Distenfeld and R. Colvett, "Skyshine Considerations for Accelerator Shielding Design," Health Physics Division, Brookhaven National Laboratory, Upton New York 11973 Undated.

through 64 of NCRP Report No. 38[42], footnote 46). A dose reduction factor of 2 was used to account for local shielding. Occupancy of buildings is assumed to occur for 2000 of the 3800 hours of AGS operation during a year. Annual dose equivalent to persons in buildings has been shown to be acceptably low.[43] One factor was conservatively not used to reduce the dose, a factor to account for a 20% increase in density of soilcrete relative to ordinary earth. This provides an extra margin of safety into the calculations.

During AGS studies, the beam dump can receive the full AGS beam. Studies are planned to use 4.9% or less of the maximum available beam and to occur at 10 GeV or less. Typically studies are conducted over several 8 hour shifts periodically throughout the running period.

Fixed Targets

In target caves and leading up to the target station, continuous scraping of beam routinely occurs, about 2%. Target caves have 3.6 m heavy concrete shielding on the top and sides. Openings to target caves are concrete, steel and earth labyrinths. Typically, only 50% of the beam interacts in the target with the remainder entering a beam stop or being transported to a sequential target. A typical beam stop has a length of 16 meters and a radius at the front end of 3 to 4 m narrowing down to 1.5 meters at the back end. Typically, beam stops are made of iron with an outer shell of 1.2 m of heavy concrete.

The shielding for the primary beam switchyard and transport lines is typically 2.4 to 3 m of heavy concrete on the top and 3 to 3.6 m on the sidewalls. Some typical target stations have received up to as much as 5×10^{13} protons per pulse repeated every 2.5 seconds, i.e. 2×10^{13} p/s.

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[42] Protection Against Neutron Radiation, NCRP Report No. 38, National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Bethesda, MD 20814 (1987).
[43] Section 6.1.7.3 of AGS SAR, dated August 11, 1993.

Typically, the inside of a target station is 2.7 m in height and 3 m in width and it varies in length. The beam height is 2 m above the floor. Up to full beam flux, 2 x 10^{13} p/s, is expected to interact in some target stations; thus, these stations are shielded with up to 3.6 m of heavy concrete on the top and 4.8 m of heavy concrete on the sides. With the exception of slightly greater losses near target caves, it is assumed that a continuous loss of 1% uniformly distributed along the beam line occurs during operations. Typically primary beam lines are 150 meters in length, which translates to a planned loss per unit time per unit length of 1.3 x 10^{9} p/m-s. An occasional brief, controlled point loss occurs, such as that from putting a flag in the beam, and is about 2%.

The shielding for the U and V line includes earth rather than heavy concrete blocks as on other parts of the experimental areas. Openings are concrete labyrinths. Normal beam losses in the transport line result from scraping 1 to 2% of the beam. In order to run the U/V transport line at full flux, 2 x 10^{13} p/s, the earth shield over the transport line was increased from 3 m to 4.8 m. The U target station is a mix of light and heavy concrete, earth and steel plate. At present the U-line is only used for low intensity exposures.

Losses and the resulting routine and fault dose rates for typical, historical[44] high energy physics experiments in Building 912 and the U and V lines are summarized in the Table 4.5.3.k. Future high intensity proton beam experiments such as MECO and KOPIO are anticipated to be run at AGS in the first decade of 2000. The same calculational methods used for other AGS experiment doses will be utilized for MECO and KOPIO shielding design. If necessary, the SAD will be updated by appending the safety analyses of these experiments and any relevant ASE requirements will be developed and approved before operation of these experiments.

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[44] AGS SAR, Sections 6.1.8 and 6.1.8.1 through 6.1.8.9, August 11, 1993.

Table 4.5.3.k Flux Loss and Radiation Level Summary for Historical Primary Beam Lines on Experimental Floor of Building 912 (Extracted Beam at 27.5 GeV)

Shield Type	**Shield Surface of Interest**	**Routine Dose Rate[45] (1×10^{14} p/s)[46,47] mrem/h**	**Fault Dose Equivalent per AGS Pulse[48,49] (1×10^{14} p/s at 0.84 Hz) mrem/pulse**
Switchyard	Top	5 - 1000	-
	Side	-	0.1 – 10
	Gate	-	1
	Side, Trench 1	-	30
	Top, Column A7	-	70
Transport Lines for A, B, C, D, U and V Line	Top	5 - 1000	-
	Side	0.5 - 50	-
	Gates	-	0.1 – 3
	Sides, Trenches	-	0.04 – 40
	Top, Column Penetrations	-	0.04 – 40
Typical Target Cave (6 m from target station)	Top	5	-
	Side	0.5	-
Typical Target Station	Top	350	-
	Side	35	-
Typical Target Stop	Top	100 – 200	-
	Side	-	20 - 40
Secondary Beam Lines		5 - 10	-
Labyrinth Openings/Gates		100 - 500	-
Trenches		50 - 200	-

[45] D. Beavis, C Target Cave Design and D Line Radiation Measurements, July 17, 1991.
[46] The dose rates are extrapolated form routine archival radiation surveys and fault studies taken during proton operations.
[47] A layer of controls are in place to limit target stations to receive below the assumed flux of 1×10^{14} p/s. This value was chosen to bound the potential routine dose rates.
[48] In appropriate areas, fault levels are detectable by radiation monitors instantaneously, and if interlocked, the beam will shut down within 9 seconds. It is estimated that three full energy beam spills may occur with this 9-second interval at the current repletion rate of 0.42 Hz. For areas where a fault may produce more than 20 mrem per fault, a system of access controls, such as barriers and locked fences are used and the area is upgraded to one of the radiation controlled areas described in the C-A OPM, Section 9.0 series.
[49] These maximum fault levels are extrapolated from fault studies with proton beam and the weakest shield locations were assumed (Reference – D. Beavis, H. Brown, I-H Chang, A. Etkin, J. W. Glenn, S. Musolino, A. Pendzick, P. Pile, K. Reece, A. Stevens, and K. Woodle, SEB Fault Studies Summary, May 3, 1990). Protection is shielding, interlocking radiation monitors, fences and access controls.

AtR

Calculations[50] of the prompt radiation dose in regions exterior to the berm over the AtR have been performed. The calculation assumes beam intensity equivalent to 2 x 10^{11} protons per bunch, and that 114 bunches are delivered to each collider ring. This is equal to the ASE intensity limit of 2.4 x 10^{13} protons per ring. The original design calculations also assumed twice the current regulatory value of the neutron quality factor. Thus, the more realistic estimates for dose, half those presented in the design calculations, are presented in this section.

Most regions of the AtR line experience very small beam loss, about 0.05% of the injected beam at a single point such as a magnet and 0.1% over the entire length of the line. A beam stop is located in the AtR line where the X and Y lines split from the W line. This dump is assumed to absorb 100 times the beam lost in the rest of the line. A summary of the calculation results is given below. The Big Bend Region is the X and Y injection arcs where the magnet elements are “dense”. The Other Regions are upstream of the injection arcs where the magnet elements are “sparse”. In the “dense” magnet regions, the generations of cascade interactions occur spatially closer to each other, thus causing higher peak fluence closer to the original interaction as compared to the “sparse” magnet regions. The dose equivalent rates were computed to be 0.13 mrem/h from the Big Bend Region and 0.08 mrem/h at Other Regions. Annual dose equivalents from each region with gold and polarized proton running are summarized in Table 4.5.3.l.

[50] A. J. Stevens, AD/RHIC/RD-83, Analysis of Radiation Levels Associated with Operation of the RHIC Transfer Line, December 1994.

Table 4.5.3.l Annual Dose Equivalent

	Big Bend Region	**Other Regions**
Au	138 mrem	81 mrem
Protons	16 mrem	9 mrem
Total	**154 mrem**	**90 mrem**

The maximum loss over 10 seconds is of interest for determining the sensitivity of Chipmunk response. The least sensitive area would be "other regions". For this case, Au is 0.72 mrem/hr and protons are 1.56 mrem/hr.

The computed dose rates on the berm over the AtR are summarized in Table 4.5.3.m below. These dose estimates were very conservatively computed and fault studies show actual doses to be much lower. Two distinct, credible cases were examined: (1) the loss of full beam on an arbitrary point fives time per year which persists for two AGS pulses, and (2) an order of magnitude higher loss than normal, 0.5% at a point and 1% over the length of the AtR line for 5% of the collider fills in a year. During operation of RHIC, Thomson Road is posted as a Controlled Area to assure that dose limits are not exceeded for untrained individuals.

Table 4.5.3.m Fault Dose Equivalent Rates

	Big Bend Region	**Other Regions**
Two AGS pulses or 4.8 x 10^{12} 28 GeV protons lost at an arbitrary point 5 times/yr	(6.3 mrem/fault) 31 mrem/yr	(3.5 mrem/fault) 17.5 mrem/yr
0.5% point loss for and 1% total loss for 5% of the fills each year	77 mrem/yr	45 mrem/yr.
Total	**108 mrem/yr**	**62.5 mrem/yr**

RHIC

Systematic beam losses at the superconducting collider are limited by the ability of the magnets to sustain their superconducting state in the presence of particle losses. Particles leaving the beam pipe deposit energy in the form of a cascade of hadronic and electromagnetic particles. These interactions result in a significant temperature rise within a few meters from the loss point. A temperature rise of more than 0.5 K is sufficient to destroy the superconducting state of the Nb-Ti wire, which is known as a quench. Several hours may be required to cool the magnets back down to the required superconducting temperature and during this time, the experimental program is stopped. The approximate energy deposition needed to initiate a magnet quench is 4 mJ/g of superconductor and can be achieved by as little as one part in 104 of the circulating beam. Because such a small amount of beam loss can cause significant disruption to the experimental program, the collider is effectively a loss free facility. Small amounts of particle losses are cleaned by collimators, beam scrappers and a rapid acting (<1 ms) beam removal system that protects the magnets from the onset of beam loss by directing the beam into the beam dumps at the 10 o'clock areas of the ring.

The Collider beam dumps on either side of the 10 o'clock intersection region accounts for about 85% of the total beam energy loss. This loss has been conservatively analyzed to show that the berm shielding is sufficient to limit the dose rate to the nearest offsite location to < 0.5 mrem/yr.[51] A small area of the shield berm over each of the beam dumps is fenced and locked to control access for ALARA purposes.

[51] Presentation to the Radiation Safety Committee on April 3, 1996 by A. J. Srevens in RSC files.

Collimators, primary and secondary, located on either side of the 8 o'clock intersection region have been examined to determine the potential dose rates from their usage.[52] Assuming that 20% of the beam in each ring interacts on the collimator and, at most, 10% of the stored beam in an hour results in dose rates well below 0.5 mrem/yr at unposted onsite and at the nearest offsite locations.

All the multi-leg penetrations in the Collider were analyzed with the method of Gollon and recalculated by Stevens[53]. The calculated results were then amended by Gollon to conform to the as-built conditions[54].

For emergency ventilation ducts, the computed doses at the berm surfaces range from 25 to 416 mrem. At the vent fan covers, at least 3 feet above the berm, the doses range from 14 to 238 mrem. Those areas that have excessive dose are within fenced and posted areas that are locked to prevent entry during Collider operations.

Dose calculations for access and emergency egress labyrinths and escape hatches show that doses range from 1 to 35 mrem.

There are a number of straight through penetrations into Collider beam enclosures. They are cylindrical shafts used for survey and large rectangular shafts on either side of the 6, 8, 10 and 12 o'clock experimental halls to permit cryogenic piping to bypass the experiments. These calculations[55] result in doses at penetration exits that range from 6 rem for a large rectangular cryogenic piping shaft, to 110 mrem for 12-inch cylindrical shaft. It is noted that for a person standing besides the opening instead of directly over it, the dose would be a factor of 10 lower. To prevent the possibility of causing these doses, personnel are excluded from these shafts by a 6

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[52] A. J. Stevens, AD/RHIC/RD-113, Radiation Safety Considerations Near Collimators, April 1997.
[53] RHIC SAD, Appendix 16, Shielding of Multi-Leg Penetrations into the Collider Tunnel, October 1999.
[54] P. J. Gollon, AD/RHIC/RD-76A, Amendment to Shielding of Multi-Leg Penetrations into the RHIC Collider, July 1996.
[55] RHIC SAD, Appendix 19, Evaluations of Straight Through Penetrations, October 1999.

foot fence and locked gates. These fenced areas are swept by the operating shift before allowing beam operations.

Dose rates from muons have been calculated to be very small, well below 0.5 mrem/yr at all locations[56].

TLD studies have confirmed that posting the entire RHIC facility as a Controlled Area is adequate.

4.5.3.3. Induced Residual Activity

Induced residual activity is similar at all C-A accelerators and experiments, the differences caused by the beam intensity and duration. Thus the specific activities vary. The maximum activities are produced at the AGS and target stations. These activities, which bound all others, are discussed in this section. Information on the induced residual activity of facilities other than the AGS may be found in the original SADs for those facilities.

Losses of high-energy particles during AGS acceleration can initiate reactions in beam pipes, magnets, extraction septum, and the dump/scraper. These interactions produce secondary particles such as neutrons, protons and pions. At each interaction point, the nuclei of atoms struck by the high energy primary or secondary particles fragment and result in a range of lower mass nuclei, some of which are radioactive. It was, therefore, necessary to consider the planned losses in the AGS and determine the magnitude of the radiation hazard produced by the induced activity.

The materials used in construction of the C-AD experimental areas are limited in number, the most important being iron, steel, copper, aluminum, concrete, oil and plastic. These

[56] A. Stevens, AD/RHIC-46, Radiation from Muons from RHIC, 2/1/89.

metals and materials are generally not used in their pure form; that is, they have welds, or they are alloyed with other metals, or they are parts of beam-line components. Thus, irradiation produces a variety of radionuclides in any given item. On the basis of studies on the AGS radioactive waste stream, nuclides ranging in half-life from days to years are formed in these materials. Table 4.5.3.n summarizes these nuclides.

Table 4.5.3.n Summary of AGS Radionuclide Production

Irradiated Material (Predominate Material)	**Nuclide**
Plastic, Oil	^{7}Be, ^{22}Na, ^{46}Sc, ^{54}Mn, ^{57}Co, ^{60}Co, ^{68}Ga, ^{88}Zr, ^{113}Sn, ^{124}Sb, ^{125}Sb, ^{133}Ba, ^{134}Cs, ^{207}Bi
Concrete	^{7}Be, ^{22}Na, ^{46}Sc, ^{54}Mn, ^{57}Co,^{58}Co, ^{60}Co, ^{65}Zn, ^{110}Ag, ^{134}Cs
Aluminum	^{7}Be, ^{22}Na, ^{54}Mn, ^{57}Co,^{58}Co, ^{60}Co, ^{65}Zn, ^{68}Ga, ^{95}Nb, ^{110}Ag, ^{33}Ba, ^{134}Cs
Iron, Steel	^{7}Be, ^{22}Na, ^{46}Sc, ^{54}Mn, ^{59}Fe, ^{56}Co, ^{57}Co, ^{60}Co, ^{65}Zn, ^{68}Ga, ^{75}Se, ^{95}Nb, ^{110}Ag, ^{113}Sn, ^{124}Sb, ^{125}Sb, ^{133}Ba, ^{134}Cs, ^{207}Bi
Copper	^{7}Be, ^{22}Na, ^{54}Mn, ^{57}Co,^{58}Co, ^{60}Co, ^{65}Zn, ^{68}Ga, ^{110}Ag, ^{133}Ba, ^{134}Cs

Studies[57] of beam loss and activation at the AGS have provided a prescription to predict activation and resultant exposure rate at particular locations in the AGS Ring. Residual exposure rate varies around the Ring and is presently 5 mR/h to 5 R/h. The highest levels occur at the extraction region in the F superperiod. The exposure rate in the G, H, I and J parts of the

[57] K. Brown, "Beam Loss and Induced Activation in the AGS," Accelerator Division Technical Note 337 (April 9, 1990).

AGS Ring are an order of magnitude less than in the F superperiod, and in the remaining superperiods levels are three to four orders of magnitude less. Available data at the AGS indicate that the exposure rate falls off according to the following relationship for the upstream (us) portions of superperiods:

$$X_{us} = 4.1 \times 10^{-14} E^{1.2} P \ln(1 + T/\tau)$$

where:

X_{us} = exposure rate at 30 cm, mR/h

E = proton energy, GeV

P = proton loss rate, p/h

T = irradiation time, h

τ = cooldown time, h

Assuming AGS Ring operation of 3800 hours per year, and losses as indicated in Table 4.5.3.g, maximum calculated exposure rates were determined and the results summarized in Tables 4.5.3.o and 4.5.3.p. These design calculations have been shown to be conservative based on actual radiation surveys. All work during repairs and routine maintenance and modifications is planned by the Work Planning process. Part of this planning includes a detailed radiation survey of the area where work will take place. Estimates of individual and total job dose are made and reviewed by the appropriate radiation professional before the start of work. If the expected accumulated dose exceeds a given administrative limit, an ALARA Committee review is needed to see if further actions can lower worker doses before the work can begin. This process has worked well over the last 15 years to reduce the total worker doses to a fraction of the doses received in the past.

Table 4.5.3.o Proton Beam Loss in the AGS Ring and Resultant Activation Levels (R/hr) For 3800 Hours of Operation

Loss Type	**Number of Protons Lost per Year**	**Energy (GeV)**	**Exposure Rate at 30 cm After 1 Day Cooldown**	**Exposure Rate at 30 cm After 1 Month Cooldown**	**Exposure Rate at 30 cm After 1 Year Cooldown**
Injection	$6.6x10^{19}$	2.2	9.2	3.3	0.65
Transition	$7.4x10^{18}$	7	4.2	1.5	0.3
Ejection	$7.4x10^{18}$	27.5	22	7.8	1.5
Studies	$4.2x10^{19}$	10	36	13	2.6
Sums:					
Injection Region (L20)			5.8	2.1	0.4
Dump/Scraper Region (J10)			62	22	4.4

Table 4.5.3.p Historical Experimental Area Target Activation (R/hr) For a 20 Week Irradiation Period

Target	**Target Number of 28 GeV Protons Interacting per Hour**	**Exposure Rate at 30 cm After 1 Day Cooldown**	**Exposure Rate at 30 cm After 1 Month Cooldown**	**Exposure Rate at 30 cm After 6 Months Cooldown**
A	$3.8x10^{15}$	42	15	5
B	$3.0x10^{15}$	33	12	4
B’	$7.6x10^{15}$	84	30	10
C	$7.6x10^{15}$	84	30	10
C’	$3.8x10^{15}$	42	15	5
D	$7.6x10^{15}$	84	30	10

Currently, proton fluxes are 18 times less, 1.3 x 10^{13} ppp at a 2.4 second repetition rate, than those assumed in the calculations. Thus, the current levels 1 day post shutdown, which are on the order of 5 R/h at the accessible portions of the extraction area, are in agreement with the above projected values.

A beam dump/scraper about 2 m in length at J10 serves to catch 80 to 90% of the beam loss that occurs during acceleration and extraction. The remaining loss is spread over the 7 to 8 magnets downstream. The L20 septum magnet will catch most of the injection losses. In addition to absorbing the acceleration and extraction losses, the dump/scraper provides a place to safely deposit beams not injected into the experimental areas, such as during studies. The dump steel becomes radioactive due to high energy (>20 MeV) spallation reactions. The prescription used here indicates that dump radiation exposure levels may be up to 60 R/h at 30 cm one day after shutdown following a long running period at design intensities of 1 x 10^{14} p/s.

In order to reduce these levels, a shield is placed around the dump. The shield also reduces the soil activation outside the tunnel to levels below ALARA design considerations given in the BNL SBMS Subject Area on Accelerator Safety. In order to eliminate the exposure rate hazard from residual radiation levels in the dump and shield, a temporary shield can be put in place to virtually eliminate this source of radiation exposure to nearby workers.

External beam lines and target stations are made of materials which are similar to the materials in the AGS Ring with the exception of small amounts of target materials. Using the prescription for the AGS Ring, the predicted exposure rates for a 20-week running period are shown in Table 4.5.3.p., assuming half the protons interact in the target. Targets and target caves are periodically refurbished to upgrade or change experiments. Extrapolating irradiation periods beyond 20 weeks is not assumed.

The beam fraction which does not interact with the target is either transported to the next target in line or is captured in a beam stop. Beam stops are designed with re-entrant cavities to reduce the photon exposure rate to nearby personnel who may be working in the target cave. Since the early 1970s, it was clear the major portion of the AGS radiation burden is associated with equipment failures and maintenance. Substantial effort and expense was committed to improving the operational reliability and serviceability of components, which continues to be effective in reducing the radiation burden. In 1973, when 2.3 x 10^{19} protons were accelerated, the AGS Department incurred 80 man-rem from neutrons, which reflects leakage radiation, and a 655 man-rem total. In 1989, 4.5 x 10^{19} protons were accelerated and the staff incurred 3.8 man-rem from neutrons and a 58.7 man-rem total. In 1992, we incurred a total of 24.57 man-rem. It is concluded that shielding is satisfactory and that dose is largely associated with photon exposure during repairs on failed equipment.

The C-AD as low as reasonably achievable strategy since 1973 has been as follows:

a. schedule maintenance for longest cooldown time,
b. improve reliability of vacuum system,
c. improve reliability of beamline components,
d. keep history of equipment malfunction,
e. improve injection, acceleration, and extraction methods,
f. modify shielding near trenches, columns and penetrations,
g. install quick disconnects on vacuum system and magnet, water, and power cables,
h. develop radiation hardened equipment,
i. use close coupled shielding to reduce secondaries near targets,
j. establish guidelines for area access based on radiation level,
k. train on mock-up equipment,
l. design shielding for quick removal,
m. use remote areas for storage of hot equipment,
n. compile and assess personnel exposure data,
o. institute radiation work permit system,
p. use complete magnet assemblies for quick replacement,
q. simplify target alignment and storage,
r. use self-aligning magnet stands to simplify surveying,
s. reduce density of beam components to reduce serviceability problems,
t. use remote test points to trouble shoot magnets,

u. increase the number of radiation monitoring points, and

v. provide computer integration of radiation monitoring system.

When heavy ion running occurs, activation is at least an order of magnitude lower than during high-intensity protons are run.

4.5.3.4. Activated Cooling Water

If activation of water is possible, C-A cooling water systems consist of a primary system, which is a closed system. This closed system has direct contact with the equipment or material being cooled, such as a magnet, beam dump or a target material, and can be directly irradiated by primary or secondary beam. Radioactivity is thus produced directly in the closed cooling water systems. Experience indicates that ^{7}Be and ^{3}H are the two long-lived radionuclides that are produced. The estimates indicate mCi amounts of ^{7}Be and ^{3}H are produced annually. Some secondary cooling water systems or cooling tower water may also be slightly activated depending upon the system configuration. For ^{3}H and ^{7}Be, the estimated concentrations at the end of a typical annual running period are given in Tables 4.5.3.q and 4.5.3.r for cooling tower and closed loop cooling water systems.

In addition to direct activation of water, slight amounts of radioactivity which have been induced in the magnet materials and wind up as corrosion products, are picked up in the cooling water. The current AGS systems have µCi amounts of radionuclides such as ^{54}Mn, ^{22}Na and ^{65}Zn. Activated cooling water is in closed re-circulated systems that are de-ionized, which greatly reduces the amount of dissolved and suspended corrosion products.

Tritium is always produced in conjunction with gamma emitters so a gamma detector is sufficient to monitor the effluent. In the event of an inadvertent release, gamma radiation monitors in the sanitary waste system which receives AGS effluent are designed to trigger the diversion of radioactive water away from the BNL Sewage Treatment Plant and toward a lined hold-up pond for additional sampling and treatment.

Table 4.5.3.q Typical Radioactivity Concentrations in C-AD Cooling Tower Water Systems

Cooling Tower Name	Location	Tritium Concentration (pCi/L)	Comments
Exp. System Tower No. 1	911, 912	5×10^2	No other radionuclides
Exp. System Tower No. 2	912	<MDL*	Pb-212
Exp. System Tower No. 3	912	2×10^3	No other radionuclides
Exp. System Tower No. 4	912a	2×10^3	No other radionuclides
F-10 Cooling Tower	932	<MDL	No other radionuclides
B-902 System Tower	902	1×10^3	No other radionuclides
RFMG Tower System	928	5×10^2	No other radionuclides
LINAC Tower	930	2×10^3	No other radionuclides
Booster Tower No. 5	919	2×10^3	No other radionucides
PTR Cooling Tower	919	<MDL	No other radionucides
g-2 Tower System	919	<MDL	No other radionucides
RHIC Inj. Tower No. 6	1000P	<MDL	No other radionucides
Brahms Cooling Tower	1002	<MDL	No other radionucides
RHIC RF Cooling Tower	1004	<MDL	No other radionucides
RHIC Cryo Cooling Tower No. 7	1005	<MDL	No other radionucides
STAR Cooling Tower	1006	<MDL	No other radionucides
PHENIX Cooling Tower	1008	<MDL	No other radionucides
PHOBOS Cooling Tower	1010	<MDL	No other radionucides
NSRL Cooling Tower	957	<MDL	No other radionucides
He Reliquifier Cooling Tower	1005E	<MDL	No other radionuclides

*MDL = Minimum Detectable Level, ~ 300 pCi/L for tritium

Table 4.5.3.r Typical Radioactivity Concentrations in C-AD Closed Cooling Water Systems

Water Systems Name	**Location**	**Tritium Concentration (pCi/L)**	**List of Other Isotopes**
Main Magnet Water	911	4.5×10^5	Be-7, Mn-54, Co-56, Co-57, Co-58, Co-60
Special Injection	911	4.5×10^5	Be-7, Mn-54, Co-57, Co-58, Co-60
Fast Quad	TE Bldg.	1.1×10^5	No other radionuclides
C-Line Cooling	912	1.2×10^7	Be-7, Na-22, Sc-46, Mn-54, Co-56,Co-57, Co-58, Co-60, Zn-65
RF Cavity	928, 913	2.5×10^5	No other radionuclides
SEM	928, 913, 914, 912A	5.6×10^5	Be-7, Mn-54, Co-58, Co-60
LINAC Transport	930	4.5×10^4	No other radionuclides
Beam Stop (BLIP)	946	1.2×10^6	Be-7, Mn-54
Booster Magnet	914	3.2×10^5	No other radionuclides
Booster RF Cavity	914	1.5×10^5	Be-7
Chilled Water	911,913, 914	5.5×10^5	Na-22, Mn-54
F-10 Cooling	932	1.5×10^5	No other radionuclides
PA Cooling	951	3.8×10^5	Be-7
g-2 Cooling	919	2.5×10^5	No other radionuclides
Power Room	911	7.5×10^2	No other radionuclides
Multipole Cooling	911	1.2×10^3	No other radionuclides
H-10 Cooling	H-10	< MDL*	No other radionuclides
B-944 Test	944	1×10^4	No other radionuclides
Rectifier System	928	1.5×10^3	No other radionuclides
RF Power	928	< MDL	No other radionuclides
Choke	928	5×10^3	No other radionuclides
Chilled Water	928	< MDL	No other radionuclides
Linac RF	930	2.0×10^4	No other radionuclides
10th Station	930	2.5×10^3	No other radionuclides
Linac OPUS	930	2×10^3	No other radionuclides

Table 4.5.3.r Continued - Typical Radioactivity Concentrations in C-AD Closed Cooling Water Systems

Water Systems Name	**Location**	**Tritium Concentration (pCi/L)**	**List of Other Isotopes**
Linac Cavity #1	930	2×10^3	No other radionuclides
Linac Cavity #2	930	1.5×10^4	Na-22, Na 24
Linac Cavity #3	930	2.2×10^4	Na-22, Na-24
Linac Cavity #4	930	2×10^5	Na-22, Na-24
Linac Cavity #5	930	2×10^5	Na-22, Na-24
Linac Chilled Water	930	2×10^3	No other radionuclides
B919B Test	919B	1.5×10^4	No other radionuclides
B-925 Test	925	1.5×10^4	No other radionuclides
RHIC Injection	1000P	1.0×10^4	No other radionuclides
Brahms Cooling	1002	<MDL	No other radionuclides
RHIC RF PA	1004	<MDL	No other radionuclides
RHIC Cavity	1004	<MDL	No other radionuclides
STAR Magnet	1006	<MDL	No other radionuclides
STAR MCW	1006	<MDL	No other radionuclides
STAR PS	1006	<MDL	No other radionuclides
TPC Cooling	1006	<MDL	No other radionuclides
PHENIX Magnet	1008	<MDL	No other radionuclides
PHENIX PS	1008	<MDL	No other radionuclides
PHOBOS	1010	<MDL	No other radionuclides
PTR Cooling	919	<MDL	No other radionuclides
V-Target Water	919	1×10^8	Be-7, Na-22, Co-56, Co-57, Co-59, Co-60, Zn-65
NSRL Main Magnet	957	<MDL	No other radionuclides
NSRL Power Supply	957	5.0×10^3	No other radionuclides
He Reliquifier	1005E	<MDL	No other radionuclides

*MDL = Minimum Detectable Level, ~ 300 pCi/L for tritium

The AGS practice is to monitor closed system or contact cooling water prior to discharge, and planned release of cooling water follows receipt of analytical data showing acceptable levels for all radionuclides. Additionally, the metals content is monitored in both contact and secondary cooling waters. The practice and follow-up actions for contact waters are as follows:

a. monitor for radioactivity and metals,
b. transport to C-AD Storage Tanker Trailers at Building 974 for treatment by evaporation or to the BNL Environmental and Waste Management Services Division if the radiation level is higher than allowable for direct discharge into the sanitary waste system,
c. process metals "in-line" if high,
d. discharge to the sewage treatment plant if all aspects of the State Pollution Discharge Elimination System Permit are met, and
e. contract a waste disposal facility when all else fails.

Cooling water will also contain small amounts of short-lived radio-gases, $^{15}0$ and ^{13}N. The external radiation hazard from circulating these gases with cooling water is momentary, lasting 5 to 10 minutes post shutdown of the beam.

Regarding hazards from activated animal waste for NSRL; assume an animal sample receives a near lethal dose of 500 rad (5 Gy) from 1 GeV/nucleon iron ions. This corresponds to $4x10^8$ iron-ions for a 20 cm^2 beam-size, or $2.3x10^{10}$ nucleons at 1 GeV. For soft tissues, water comprises about 80% of mass. Assume a sample is made of water, presents a 20 cm^2 area to the beam and is 20 cm long. Given a 30 millibarn (mb) cross-section for tritium production from high-energy nucleon-collisions with oxygen, the total tritium created in a sample from a 500 rad dose is 22 pCi. The activated excreta of animals is not expected to be measurable nor is it a significant radioactive hazard.

Radioactive water drained or collected from the various radioactive cooling water systems is transferred to one of three 7000-gallon tanker trailers, which are usually located at Building 974. They can be moved by truck throughout the site to facilitate transferring of water for later use, or as waste. The tankers are stainless steel and are parked inside a Suffolk County Article 12 registered secondary containment when not being used to transfer water.

Steam heat can be supplied to the tankers to heat the water to prevent freezing in the winter and to slowly evaporate the water throughout the year. The vapor contains low levels of tritium oxide from the activated cooling water systems from which it was drained.

A NESHAPs Assessment was conducted for this air release. The first evaluation was conducted in October 2000, by BNL ESD as part of the C-A Department's implementation of the ISO14001 EMS requirements. In that evaluation, only releases during the cold weather were considered.[58] A second NESHAPs evaluation was completed in June 2001 when the decision was made to maintain the tanker water heated all year in order to minimize the volume of wastewater for waste minimization. This evaluation assumed 25,000 gallons of water was evaporated each year.[59] The release was computed to cause an insignificant annual dose to the offsite maximally exposed individual of the public, MEI, of 0.0000864 mrem/yr. This release has no adverse public or environmental effects. It is noted that the MEI dose is directly proportional to the volume of water released, so even if the release was 50,000 gallons/yr, the MEI dose would only be 0.0001728 mrem/yr. Water tanker evaporation dose to workers has been evaluated to be insignificant.[60]

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[58] Memorandum from G. Schroeder to P. Callegari, dated October 10, 2000
[59] Memorandum from B. Hooda to P. Lang, dated June 25, 2001
[60] R. Karol, Radiation Hazards From C-A Water Tanker Tritiated Water Evaporation, March 6, 2002

4.5.3.5. Soil Activation and Groundwater Contamination

The technique for estimating groundwater activation is described in the various original C-AD facility SARs and SADs. For each significant beam loss location which can activate soil shielding, the time-averaged transport of ^{3}H and ^{22}Na concentrations from the position of their creation to the water table by the leaching action of rainwater is estimated. This leachate concentration is required to be less than 5% of the drinking water standard as per the BNL Subject Area on Accelerator Safety.[61] The drinking water standard is 20,000 pCi/L for ^{3}H and 400 pCi/L for ^{22}Na. If this condition is not met, then impermeable caps are required to cover the soil. These caps act like umbrellas to prevent leaching of the radionuclides from the soil to the water table.

The quantity calculated to determine the soil radionuclide content is the CASIM "star density" or inelastic collision density. This is the interaction density of hadrons above about 47 MeV. Calculations have shown that approximately 0.075 ^{3}H and 0.02 ^{22}Na atoms are created per CASIM star, adjusted to a 20 MeV threshold.

Summaries of known beam loss locations and groundwater contamination issues at C-AD facilities have been written.[62,63,64] Based upon the groundwater flow direction, soil pore velocity, and dispersion, it would take greater than 20 years for any contaminated groundwater to reach the BNL southern boundary, and thus there are no possible adverse health effects to the public. Several onsite potable water supply wells could be contaminated within a time frame of years

[61] Accelerator Safety Subject Area, Design Practice for Known Beam Loss Locations.
[62] Memorandum for D. Lowenstein and E. Lessard to P. Paul, Beam Stops and Other Sources of Soil Activation at the AGS Complex, August 7, 1998.
[63] Investigation of the Tritium Release at Location Upgradient of BNL Well 054-067, December 10, 1999.
[64] Brookhaven National Laboratory g-2 Tritium Plume – AOC 16T Engineering Evaluation/Cost Analysis, December 2003.

following groundwater contamination caused by C-AD operations. Again, there are no adverse health effects to onsite personnel. A large number of groundwater monitoring wells are positioned to monitor C-AD facilities that contain activated soil shielding. This active surveillance program allows for rapid detection of a problem and quick response to stop the source. Furthermore, BNL is controlling the pumping of the most vulnerable supply wells onsite to prevent drawing contaminants toward them. (e.g., supply well #10 located east of the AGS experimental areas).

Groundwater contamination is an environmental issue related to the BNL EMS program where we are committed to protect our natural resources and is not a health issue to workers, onsite personnel or the public.

4.5.3.6.Activated Air

The main source of air activation is the interaction of primary and secondary particles directly with air nuclei. Air contains approximately 78.1 % N_2, 21% O_2, 0.5 % ^{40}Ar, 0.3 % ^{15}N, and 0.04 ^{18}O. Low energy beams are contained in the vacuum pipe of the accelerator or beam line and air activation with these beam types is low. At higher energies, especially protons, and when air gaps exist where the beam passes through air directly, air activation becomes more important. In addition, the large multiplicity of secondary particles produced as part of the cascade, both electronic and hadronic, processes can produce air activation even when the beam is contained in the vacuum line.

In general, the positron emitters ^{11}C ($t_{½}$ of 20.3 m), ^{13}N ($t_{½}$ of 9.97 m) and ^{15}O ($t_{½}$ of 122.2 s), along with ^{41}Ar ($t_{½}$ of 1.83 h, produced by thermal neutron absorption in ^{40}Ar) are most frequently observed.

By design, the Linac, Tandem, TtB, Booster, AGS, Fixed Target caves, U and V Lines, AtR and RHIC do not have forced exhaust ventilation during operation in order to minimize the release of activated air. The air activation is minimized by passing ion beams through vacuum tubes and minimizing the beam path through air in target caves. Helium-filled bags may be used in the beam path not enclosed in vacuum to reduce interactions and multiple scattering.

Following beam operations, fixed waiting intervals are specified in the C-AD OPM to enter primary areas in order to assure that doses to workers and experimenters are ALARA. The waiting intervals depend upon the ion beam species and the beam intensity prior to entry into the primary area.

For the NSRL facility, the Target Room in Building 958 is continuously ventilated to reduce odors from the specimens. The air activation estimate in the Target Room was made using MCNPX. The beam path length in air is 28 feet including the length of the re-entrant beam dump cavity. The room-averaged hadron flux greater than 20 MeV from interactions is 2.1×10^{-6} per cm^2 per incident 2-GeV proton, and the thermal neutron flux is 3.4×10^{-6} per cm^2 per proton. However, the room averaged flux of the incident beam particles is 6.8×10^{-6} per cm^2 per proton, which dominates the activation of air.

Given these fluxes, concentrations of various radionuclides were estimated using appropriate cross sections. For ^{39}Cl and ^{38}Cl, produced by spallation reactions with the argon in Target Room air, cross sections were estimated from Rudstram[65]. These were included because

[65] Barbier, M., Induced Radioactivity, Section 2.3. North-Holland Publishing Company, 1969.

they are sometimes detected in air samples at BNL accelerators. With the maximum annual energy flux of 3×10^{16} GeV per year on the beam stop given in Table 4.5.3.e, Table 4.5.3.s summarizes the annual-activity concentrations averaged over the Target Room volume which were conservatively computed ignoring radioactive decay and Target Room ventilation.

Table 4.5.3.s Annual-Activity Concentration Averaged over Target Room Volume And Annual Production Rate of Air Activation Products

Radionuclide of Interest	Volume Averaged Annual-Activity Concentration, Ci/cc	Annual Production Rate, Ci/yr
^{41}Ar	2.2×10^{-11}	2.6×10^{-3}
^{39}Cl	1.2×10^{-16}	1.4×10^{-8}
^{38}Cl	4.3×10^{-16}	4.9×10^{-8}
^{35}S	1.4×10^{-15}	1.6×10^{-7}
^{32}P	9.1×10^{-15}	1.0×10^{-6}
^{28}Al	7.0×10^{-13}	8.1×10^{-5}
^{22}Na	5.6×10^{-17}	6.3×10^{-9}
^{15}O	6.7×10^{-9}	7.4×10^{-1}
^{14}O	2.8×10^{-10}	3.2×10^{-2}
^{13}N	1.6×10^{-9}	1.8×10^{-1}
^{11}C	7.0×10^{-10}	8.1×10^{-2}
^{7}Be	1.9×10^{-13}	2.1×10^{-5}
^{3}H	7.7×10^{-15}	8.8×10^{-7}

Given these radionuclide quantities, the dose to the maximally exposed individual, MEI, of the public has been estimated using the Clean Air Act Code CAP88-PC. The standard BNL site-specific model was utilized with 10-year average wind rose, temperature, and precipitation and CY 2000 population data. The CAP88-PC model is designed to model routine, continuous airborne radioactive emissions that occur over the course of a year. The radionuclides listed in Table 4.5.3.s were modeled as if they were released in this manner. Aluminum-28 and oxygen-14 are not included in the CAP88-PC radionuclide library and thus were not included in the model. However, the source terms and half-lives of these radionuclides are so small that their exclusion has no affect on the conclusions of the evaluation. Chlorine-39 and chlorine-38 were also not included because their effect has no affect on the conclusion.

The calculation showed that the dose to the BNL site maximally exposed individual of the public at the northeastern site boundary is 9.7×10^{-6} mrem/yr.[66] This dose is six orders of magnitude below the 10 mrem/yr limit specified in 40CFR61, Subpart H, and a factor of ten-thousand times less than the 0.1 mrem/yr limit that triggers the NESHAPs permitting process. Therefore, no application for a permit was required for the NSRL and continuous monitoring of the release point is not required.

Normally, the Target Room is ventilated continuously to reduce odors from the biological specimens. The ventilation system will maintain the radionuclide concentrations at insignificant values in the Target Room. If the ventilation is off and irradiations and entries are still made over an 8-hour interval, the dose to an individual who spends an hour in the Target Room would be a small fraction of a mrem.[67] Thus, there are no significant hazards from loss of Target Room ventilation.

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[66] http://www.rhichome.bnl.gov/AGS/Accel/SND/BAF/BAFSADAppendix4.pdf, Appendix 4, BAF SAD, G. Schreoder, NSRL Facility/Process Radionuclide Evaluation, January 4, 2001.

[67] R. Karol, Dose to Individual in BAF Target Room Following Ventilation Failure, March 19, 2001 (Revised 4/19/01).

4.5.3.7. Skyshine

Radiation that extends several hundred meters from an accelerator shield or the top of an accelerator building is termed skyshine. Escaping neutrons through thin parts of the shield or roof causes skyshine. Roof shields are inaccessible, via access controls, during operations. The upward neutrons scatter in the air above the complex, and mixed gamma-neutron radiation arrives back at ground level. Ongoing monitoring shows that skyshine is a minor contribution to the annual dose to the public and workers. Annual environmental radiation measurements for offsite areas show that it is not measurable above natural background radiation levels. The measured skyshine levels are summarized in the BNL Site Environmental Report produced by the BNL Environmental and Waste Management Services Division.

Linac

Skyshine from the Linac beam is not a significant contributor to external dose due to the relatively low energy beam and the shield thickness. See the discussion later in this section regarding Linac to Booster injection skyshine for more details.

Tandem and TtB

Skyshine for the Tandem and TtB line is insignificant due to the very low particle energies.

Booster

The dose equivalent from skyshine due to neutrons emitted from the surface of an overlying beam line shield is given by Stevenson.[68] Neutrons emerge from the top of the shield and contribute to dose equivalent on the ground several hundred to several thousand meters away through interactions in the air column above the shield. The analytical function which describes this is:

$$H(r) = 3 \text{ x } 10^{-13}\, e^{-kr}/r^2$$

where H is the dose equivalent in rem per neutron moving upward through the shield at distance r from the source, k is the volume macroscopic dose-reduction cross section for skyshine radiation for neutron interactions in air, and r is distance from the source in meters. As deduced from Stevenson in Figure 7 of his report and inverting the value for effective absorption length, k equals $1.25\text{x}10^{-3}$ m^{-1} for 1.5 GeV neutrons, nominal Booster extraction energy, and $2\text{x}10^{-3}$ m^{-1} for 200 MeV neutrons, the injection energy from Linac.

A summary of the number of neutrons emitted from several locations which contribute 5 mrem at the site boundary and 25 mrem at onsite buildings that are uncontrolled areas or non-C-A facilities is given in Table 4.5.3.t. The closest non-C-AD uncontrolled location with full-time occupancy is the old BGRR complex. The closest uncontrolled C-AD facility is Building 911. Buildings 919 and 931 (BLIP) are both posted controlled areas.

[68] G.R. Stevenson, R.H. Thomas, "A Simple Procedure for the Estimation of Neutron Skyshine from Proton Accelerators", Health Phys. 46, 115-122 (1984).

Table 4.5.3.t Number of Neutrons Emitted from the Top of the Booster which Produce 5 mrem at the Site Boundary and 25 mrem at other Uncontrolled Areas or Non-C-AD Facilities

Location (Design Goal)	**Occupancy Fraction and Distance (m)**	**Injection (200 MeV)**	**Extraction and Studies (1.5 GeV)**
Site Boundary (5 mrem)	1, 1100 m	1.8×10^{17}	8.0×10^{16}
Former BGRR Complex (25 mrem)	1/3, 520 m	3.8×10^{18}	2.6×10^{18}
Building 911 (25 mrem)	1/3, 370 m	1.4×10^{18}	1.1×10^{18}
Building 919 (25 mrem)	1/3, 150 m	1.5×10^{17}	1.4×10^{17}
Building 931 (25 mrem)	1/6, 80 m	7.5×10^{15}	7.1×10^{16}

On-site facilities are of slightly greater significance than the site boundary. This is dependent on assumptions regarding local shielding and energy of scattered neutrons. The neutrons which scatter off the air back to the ground toward these buildings have an energy distribution nearly equivalent to the fast flux from a PoBe source (>0.5 MeV) and 0.5 feet of concrete or equivalent local shielding attenuates the neutrons by a factor of 20. This attenuation from local shielding increases the number of leakage neutrons that correspond to a given dose equivalent at a given, distant location and is included in the onsite estimates for skyshine. Occupancy of the Building 931 facility (BLIP), which is at 80 m, is during the day shift only, about 4 hours per shift according to Medical Department staff who has operated the facility for many years. This corresponds to one sixth of a Booster operating day. Occupancy of the former BGRR complex, Building 911 and Building 919 is 8 hours per day, which is one third of an operating day for the Booster. Therefore, it is reasonable to assume that Building 931 is the most restrictive location and that 7×10^{16} neutrons is the limiting design for neutrons contributing to skyshine from the Booster each year. Full-time occupancy and zero local shielding are conservatively assumed for the site boundary location.

ICRP Publication 21[69] lists the dose equivalent per unit neutron fluence for l/E spectra versus maximum neutron energy. If the analytical function by Stevenson is used to estimate dose equivalent from skyshine, the maximum neutron energy should be estimated from the maximum proton energy of the accelerator. For 200 MeV and 1.5 GeV, the conversion factors deduced from ICRP 21 are 8.1×10^7 and 5.9×10^7 neutron/cm^2 per rem respectively. A mean value of 7×10^7 neutrons/cm^2 per rem is used here. This conversion factor and the annual areal-dose design goal, which incorporates the design limit of 7×10^{16} neutrons from Table 4.5.3.t, are given in Table 4.5.3.u.

Table 4.5.3.u Total Annual Areal Dose Goal (rem-cm^2)

Shield Material	**n/cm^2-rem**	**rem/cm^2**
Earth or Concrete	7×10^7	1×10^9

In order to ensure that the design goal is met, an estimate of the annual area1 dose is computed based on 1) a Booster operating schedule of 200 days per year, 2) the shielding configuration near the dump and the extraction septum, and 3) the planned loss assumptions. Polarized proton and heavy ion modes make up 100 days of the annual running period, and unpolarized proton running makes up 100 days. Additionally, Booster studies require 70 operating days and about one third of the scheduled operating hours during those days. Based on

[69] International Commission on Radiological Protection, Data for Protection Against Ionizing Radiation from External Sources: Supplement to ICRP Publication 15, ICRP Publication 21 [Pergamon Press, October (1973)].

studies at the AGS Ring[70], skyshine neutrons from a point source, such as the losses at the extraction septum and the dump/scraper, emerge from a berm surface area of $2x10^2$ m^2. For perspective, the top of Building 914 downstream of the septum is about $2x10^2$ m^2, and the top of the Booster Ring is about $2x10^3$ m2. Using a loss area of $2x10^2$ m^2, and the routine peak dose rates given in Table 4.5.3.t, the computed areal-dose equivalent is $3.4x10^7$ rem-cm^2 near the extraction septum and $9.3x10^6$ rem-cm^2 near the dump/scraper. The sum is 4.3 x 10^7 rem-cm^2 which is well within the design goal of $1x10^9$ rem-cm^2. Location specific estimates of annual dose from skyshine are given in Table 4.5.3.v. These estimates are overly conservative and TLD studies show that actual values are significantly lower.

[70] K. Brown, J. Glenn, S. Musolino, A. Stevens, R. Thern, "AGS Shield Tests", AGS Studies Report Number 245 (November 4, 1988).

Table 4.5.3.v Flux Loss and Sky Shine Exposure Summary

Loss Flux Location	Nucleon Energy (MeV)	Annual Areal Dose (200 m^2)	Corresponding Number of Leakage Neutrons (rem-cm^2/y)	Site Boundary Dose (mrem/y)	Closest Occupied Building Dose (mrem/y)
Injection dump/scraper	200	2.8×10^{3}	2.0×10^{11}	6×10^{-6}	7×10^{-5}
Acceleration dump/scrapper	700	9.6×10^{5}	6.7×10^{13}	4×10^{-3}	2×10^{-2}
Extraction septum	1500	3.4×10^{7}	2.4×10^{15}	2×10^{-1}	9×10^{-1}
Heavy ions stripper	1066	2.4×10^{7}	1.7×10^{15}	1×10^{-1}	6×10^{-1}
Studies dump/scrapper	1500	8.4×10^{6}	5.9×10^{14}	4×10^{-2}	2×10^{-1}
Total (assuming protons for 200d/y)		**4.3×10^{7}**	**3.1×10^{15}**	**2×10^{-1}**	**1**

Building 931 is the closest occupied on-site facility at 80 m to the various sources identified in Table 4.5.3.v, and personnel are expected to receive a total of no more than 1 mrem per year from skyshine. The skyshine dose decreases with distance from the source and diminishes by a factor of at least 4 at 150 m to Building 919 and by a factor of at least 30 at 370 m to Building 911. Given the accuracy of the skyshine analytical function and TLD studies, it is reasonable to conclude that the annual skyshine dose at nearby locations, such as Buildings 919, 925, 911, 928, 929 and 902, will be much less than 1 mrem.

Due to the proximity and elevation of Building 931 (BLIP) particle interactions in the earth on top of Building 914 and on top of the Booster Ring near the dump/scraper at D6 are a source of more radiation at Building 931 than radiation from high energy particle interactions in the column of air above the Booster. According to Table 4.3.5.v, about 3×10^{15} neutrons are estimated to leave the surfaces of Booster during the year. Radiation that originates at the surface realistically diffuses outward, rather than all going straight up into the air. About 50 mrem at Building 931 is estimated for a hemispherical source at the Booster surface. Adjusting for occupancy, the annual dose at Building 931 is 10 mrem from groundshine. Assuming full-time occupancy at Building 931 results in 20 mrem per year. Thus groundshine plus skyshine contributions still results in exposures below the ALARA design considerations. This additional exposure to neutrons from groundshine diminishes rapidly at distances greater than Building 931 since other buildings, earth and obstructions absorb or scatter the groundshine neutrons.

NSRL

Both the skyshine dose-rate estimate and the groundwater activation estimate, described later in this Chapter, are sensitive to targeting conditions. The maximum flux values listed in Table 4.5.3.e assume that the beam can be incident on either a target or the beam stop 100% of the time.

The skyshine dose rate was determined by first estimating the number of neutrons greater than 20 MeV emerging from the earthen berm surface, then applying a skyshine formula developed from past measurements made at the AGS. The estimate of the number of neutrons was made from CASIM calculations performed at 2 GeV incident energy in a simplified approximation of the geometry, a geometry that overestimates the emerging neutrons. Specifically, the berm was assumed to have a circular transverse cross-section, and the neutrons were summed over a ±45° section centered on the beam line.

CASIM estimates were made with both the beam incident on the beam dump and on a 0.25 interaction length plastic target. The worst case was with the target present, where the number of neutrons greater than 20 MeV per 2 GeV proton is 2×10^{-5}. For 1.5×10^{16} 2-GeV protons per year, the skyshine formula becomes:

$$rem/\,year = \frac{0.125 \times e^{-D/600} \times (1 - e^{-D/47})}{D^2}$$

where D is the lateral distance from the source to the dose point of interest in meters.

The closest building that at times is uncontrolled is Building 919 at D = 70 m. At this distance, the computed dose rate is about 0.02 mrem/yr.

AGS and Fixed Targets

Simple analytical functions[71,72,73] are used in order to estimate on-site and off-site dose equivalent. The external exposure limits of 5 mrem/y offsite and 25 mrem/y at uncontrolled onsite buildings are the basis for and are related to secondary design goals such as the thickness

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[71] G.R. Stevenson, R.H. Thomas, "A Simple Procedure for the Estimation of Neutron Skyshine from Proton Accelerators", Health Phys. 46, 115-122 (1984).
[72] K. Tesch, "A Simple Estimation of the Lateral Shielding for Proton Accelerators in the Energy Range 50 to 1000 MeV", Radiation Protection Dosimetry 11, 165-172 (1985).
[73] K. Tesch, "Comments on the Transverse Shielding of Proton Accelerators", Health Phys. 44, 79-82 (1983).

of shield needed to meet those dose goals. The following is a description of the methods used to derive secondary design goals in five steps, and a summary.

1. Dose Equivalent From Neutrons Emitted In An Upward Direction

The dose equivalent from skyshine due to neutrons emitted from the surface of an overlying beam line shield is given by Stevenson. Neutrons emerge from the top of the shield and contribute to dose equivalent on the ground several hundred to several thousand meters away as a result of interactions in the air column above the shield. The analytical function which describes this is:

$$H(r) = 3 \times 10^{-13}\, e^{-kr}/r^2$$

where H is the dose equivalent at ground level from secondary skyshine radiations in rem per neutron-emitted upward at distance r from the source, k is the volume macroscopic dose reduction cross section for skyshine radiation produced from neutron interactions in air, and r is distance from the source in meters. As deduced from Stevenson, $k = 1.18 \times 10^{-3}\ m^{-1}$ for 28.5 GeV maximum energy neutrons. Based on Stevenson, the dose equivalent calculated for distances less than 400 meters is overestimated, and according to their graphs, probably by a factor of 2 for 28.5 GeV.

2. Number of Upward Neutrons Which Yield the Annual Dose Design Goal

A summary of the number of neutrons emitted from several locations which lead to 5 mrem and 25 mrem at areas of interest is given in Table 4.5.3.w. The closest non-C-AD uncontrolled location with full-time occupancy is the retired Brookhaven Graphite Research Reactor (BGRR) complex. The closest uncontrolled C-AD facility is Building 911. Occupancy at the BGRR complex and Building 911 is assumed to be 40 hours out of 168 hours per week or 25% of a running period.

Table 4.5.3.w Number of Neutrons Emitted from the Top of D, A, B or C Lines Which Produce 5 mrem at the Site Boundary and 25 mrem at Other Uncontrolled and Fully Occupied Locations

Location (Design Goal)	**Occupancy Factor**	**D-Line (distance)**	**A-Line (distance)**	**B-Line (distance)**	**C-Line (distance)**
Site Boundary (5 mrem)	1.0	1.7×10^{17} (1400 m)	1.7×10^{17} (1400 m)	1.7×10^{17} (1400 m)	1.7×10^{17} (1400 m)
BGRR Complex (25 mrem)	¼	8.6×10^{17} (300 m)	1.2×10^{18} (350 m)	1.7×10^{18} (400 m)	2.4×10^{18} (450 m)
Building 911 (25 mrem)	¼	1.8×10^{17} (150 m)	3.4×10^{17} (200 m)	5.6×10^{17} (250 m)	8.6×10^{17} (300 m)
Building 923 (25 mrem)	¼	3.6×10^{17} (250 m)	3.4×10^{17} (200 m)	1.8×10^{17} (150 m)	7.6×10^{16} (100 m)

On-site facilities are of greater significance than the site boundary; however, this depends on assumptions regarding local shielding, building classification with regard to radiation safety, and energy of skyshine radiations. Building 923 is a controlled area, which contains radioactive materials. The nearest uncontrolled building is Building 911 which is closest to the D line. Assuming that the skyshine flux at Building 911 is equivalent in energy to the fast flux of neutrons from a PoBe source (>0.5 MeV), 30 cm of concrete will attenuate the skyshine by a factor of about 20. This factor of 20, used for onsite building local shielding raises the number of upward neutrons causing 25 mrem at a distance to 1.8×10^{17}. This is approximately the same as the site boundary goal. Therefore, it is reasonable to assume that the site boundary goal, 1.7×10^{17} neutrons, is the limiting value for upward neutrons for the AGS Ring and Experimental Areas.

3. Total Areal-Dose Equivalent Goal (rem-cm^2)

ICRP Publication 21[74] lists the dose equivalent per unit neutron fluence for 1/E spectra versus maximum neutron energy. If the analytical function by Stevenson is to be used to estimate dose equivalent from skyshine, the maximum neutron energy should be estimated from the maximum proton energy of the accelerator. For 28.5 GeV, the conversion factor deduced from ICRP 21 is 2 x 10^7 neutron/cm^2 per rem. Stevenson indicates that a 1/E spectrum applies to dry concrete, but he also indicates that there are fewer low-energy neutrons from earth shields since earth contains water.[75] On the other hand, Stevenson tabulates measurements which indicate that 2 x 10^7 neutrons/cm^2 per rem is appropriate for a neutron spectrum from high-energy proton accelerators with thick earth shields. In that same report, he gives a value of 1.5 x 10^8 neutrons/cm^2 per rem for iron, and this value reflects the fact that iron is transparent to low-energy neutrons. These conversion factors and the design goal which incorporates the value of 1.7 x 10^{17} neutrons from Step 1 are given in Table 4.5.3.x.

Table 4.5.3.x Neutrons Per Unit Area Per Unit Dose Equivalent at the Surface of a Thick Shield for the Condition of 28.5 GeV Protons Incident on a Target Behind the Lateral Shield and Total Annual Areal Dose Equivalent Goal (rem-cm)

Shield Material	**n/cm^2-rem**	**rem-cm^2**
Concrete	$2x10^7$	$8.5x10^9$
Earth	$2x10^7$	$8.5x10^9$
Iron	$1.5x10^8$	$1.1x10^9$

[74] International Commission on Radiological Protection, Data for Protection Against Ionizing Radiation from External Sources: Supplement to ICRP Publication 15, ICRP Publication 21 [Pergamon Press, October (1973)].
[75] G.R. Stevenson, "Dose Equivalent Per Star in Hadron Cascade Calculations", Divisional Report, European Organization for Nuclear Research, TIS-RP/173 (May 26, 1986).

Therefore, on-site and offsite external dose rate design goals are met if no more than 8.5 x 10^9 rem-cm^2 are allowed at the outer shield surfaces during the annual proton running period and if concrete or earth are used at the outer parts of the shield wall.

4. Dose Rate at the Surface of the Outer Shield Wall Per Proton Per Second Stopped behind the Shield Wall

There are simple analytical relationships reported by Tesch[76] for relating the surface dose equivalent to proton loss behind shielding, and these can be used to interpret shielding limitations imposed by the design goal of 8.5 x 10^9 rem-cm^2. For these calculations, the distance from the target to the inner surface of the overlying shield was assumed to be 1 m. In performing shield calculations, integration is carried out over the overlying shield area which in many cases can be assumed to be over a ± 45º vertical angle. Lateral shield surface dose rates at the AGS are best approximated by a line source inside the ring instead of a point source when using the Tesch analytical functions. That is, the ring's beam loss is not really assumed to be a point, and rather it is a line about 16 m long. This is borne out by dose rate measurements at the surface of the AGS Ring following a planned loss, and by activation studies inside the tunnel. In order to account for the additional shielding offered by a magnet section, the mean chord length of magnets in the vertical angle of ± 45º is assumed to be 42 cm. In Table 4.5.3.y, the dose rate in mrem/h per proton lost per second offered by 3 different types of common AGS shielding arrangements is shown: 1) an overlying shield of 42 cm of magnet iron and heavy concrete in column 2, 2) 42 cm of magnet iron and soil in column 3, and 3) 42 cm of magnet iron, varying thick-nesses of iron plate plus 60 cm of heavy concrete at the outer surface in column 4.

[76] K. Tesch, "A Simple Estimation of the Lateral Shielding for Proton Accelerators in the Energy Range 50 to 1000 MeV", Radiation Protection Dosimetry 11, 165-172 (1985).

Table 4.5.3.y Dose Equivalent Rate at the Surface of a Lateral Shield from 28.5 GeV Protons for Different Overlying Materials

Total Thickness of Shield[a], cm (ft)	**Heavy (Ilmenite loaded) Concrete**	**Earth**	**Iron Plate (with 2 ft of heavy concrete outside)**
300 (10)	5.5×10^{-11}	1.4×10^{-9}	1.9×10^{-16}
360 (12)	8.4×10^{-12}	4.4×10^{-10}	2.6×10^{-18}
450 (15)	5.4×10^{-13}	7.4×10^{-11}	4.2×10^{-21}
600 (20)	5.3×10^{-16}	4.4×10^{-12}	1.0×10^{-25}

a: The shield thickness listed here does not include the 42 cm of magnet iron; however, the effect of magnet iron is included in the estimate of dose rate.

5. Average Surface Dose Rates Necessary to Meet Design Goals

Three assumptions are needed to estimate areal dose and average shield surface dose rate in order to meet design goals:

1) a running period of 20 weeks at 5×10^{13} protons per pulse at 28.5 GeV and 1 pulse every 2.5 seconds; that is, 2.4×10^{20} total protons at the average rate of 2.0×10^{13} p/s,

2) each beam line is designed to take 2.4×10^{20} protons per annual running period (this is the projected maximum design, most programs assigned to a beam line take only a portion of the full beam), and

3) upward neutrons from a point source of protons emerge from a shield surface area of 1.9×10^{6} cm^2 (2000 ft^2). The neutron leakage of the AGS Ring was measured in the J superperiod using the J19 flip target as a point source. The target was about 700 cm (23 ft) below

the shield top. The effective area of the neutron emission was estimated using plots of surface radiation level versus position both transversely and longitudinally outside the shield top.[77]

Based on these assumptions, the following dose rates at the surface of a heavy concrete shield and the annual areal doses are estimated and listed in Table 4.5.3.z.

Table 4.5.3.z Lateral Shield Thickness Versus Surface Dose Equivalent Rate and Areal Dose Equivalent for 2.4 x 10^{20} Protons in an AGS Beam Line (Sect. 4.1.1)

Thickness of Heavy Concrete cm, (ft)	**Surface Dose Rate mrem/h**	**Annual Areal Dose Rem-cm^2**
300 (10)	1.1×10^3	7.0×10^9
360 (12)	1.7×10^2	1.0×10^9
450 (15)	1.1×10^1	7.0×10^7
600 (20)	4.4×10^{-4}	2.8×10^3

While the table shows heavy concrete, other materials may be used. In general, 1 foot of heavy concrete (density 3.5 g/cm^3) may be substituted for 1.6 feet of earth (density 1.8 g/cm^3), for 1.25 feet of concrete (density 2.3 g/cm^3) or for 0.5 feet of iron. If iron is used as a lateral shield, the outer 2 feet must be concrete or earth since iron is transparent to low-energy neutrons.

The total annual areal dose goal, 8.5 x 10^9 rem-cm, may be met by ensuring that the planned locations for beam loss have at least 300 cm or 10 ft of heavy concrete above them or the equivalent thickness of other materials. This is true for the known loss points for the known small fraction of the beam in the AGS Ring which are shielded by a mixture of sand and soilcrete to a thickness of 690 cm or 23 ft, which is about 300 cm equivalent heavy concrete, and for the

[77] K. Brown, J. Glenn, S. Musolino, A. Stevens, R. Thern, "AGS Shield Tests", AGS Studies Report Number 245 (November 4, 1988).

experimental target areas which are typically shielded with at least 360 cm of heavy concrete over target caves. Based on these thicknesses, the AGS facilities are designed to achieve only a small fraction of the annual areal dose goal; i.e., the present shielding would allow at least 8 times more protons per year while satisfying the annual limit of 8.5×10^9 rem-cm^2 for this conservative calculation.

Not all protons will be stopped at the targets or well-defined loss points; some are lost during transport. The maximum level for a full fault dose rate was considered since the design goal of no more than 20 mrem per full-fault event in an uncontrolled area is to be adhered to. Typically, the shielding on the AGS Ring and the transport lines allows these areas to experience a maximum fault dose rate is less than 5 rem in 1 hour.

AtR

Skyshine, from normal injection operation and faults in the AtR line, was computed to be 0.003 mrem/yr at the closest occupied building, which is 1005S, and 0.0001 mrem/yr at the closest site boundary. Skyshine from the AtR beam dump during set-up and studies was found to be 1.9 mrem/yr at Thompson Road, which is posted as a Controlled Area during RHIC operations, 1.6 mrem/yr at the AtR power supply Building 1000P, 0.006 mrem/yr at Building 1005S and 0.00023 at the closest site boundary.

RHIC

Skyshine dose from routine RHIC operations at non-posted areas is negligible. Building 1005S would receive 0.0028 mrem/yr and the closest site boundary 0.0001 mrem/y. During machine setup and studies, conservatively computed doses are 0.006 mrem/yr at Building 1005S and 0.00023 mrem/yr at the closest site boundary.[78]

Both the collimators and beam stops are intended locations for beam loss. The Collider beam stops are located on either side of the 10 o'clock intersection region. They account for about 85% of the total loss of beam energy[79,80]. The dose equivalent to the closest site boundary from operation of these dumps is <0.5 mrem/year. The areas on the collider berm that are above the dumps are fenced and controlled as Radiation Areas to exclude non-radiation workers.

Skyshine from the operation of the dumps was computed to be 0.4 mrem/yr at William Floyd Parkway, the low occupied shortest off-site distance and about 1.3 mrem/yr to the closest onsite building, 1101, which is inside the Controlled Area.

The primary beam collimators are located on either side of the 8 o'clock intersection region. The dose calculation assumed that 20% of the beam in each ring interacts on the collimator and at most, 10% of the stored beam in an hour[81]. Because of the radiation levels on the berm following routine and faulted losses, the area is fenced to exclude non-radiation workers. The dose at William Floyd Parkway is <0.5 mrem/yr and to the nearest onsite building, 1101 is 0.55 mrem/yr.

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[78] AD/RHIC/RD-83, A. J. Stevens, Analysis of Radiation Levels Associated with Operation of the RHIC Transfer Line, December 1994.
[79] A. J. Stevens, AD/RHIC/RD-48, Radiation Environment and Induced Activity Near the RHIC Internal Beam Dump, November 1992.
[80] A. J. Stevens, Estimate of Dose Rate Close to the C-Dump Core from Induced Activity, August 8, 1995.
[81] A. J. Stevens, AD/RHIC/RD-113, Radiation Safety Issues Near Collimators, April 1997.

4.5.4. Oxygen Deficiency Hazards

OSHA defines an oxygen deficient atmosphere in 29CFR1910.146 as atmospheres containing less than 19.5% oxygen by volume. Normal atmospheres contain ~21% oxygen. Actual effects from oxygen deficient atmospheres do not begin until the concentration falls to ~17%. If a small number of workers are exposed to potential oxygen deficient atmospheres, it is cost effective to use conservative controls for protection. However, with large exposed populations it is necessary to better establish controls at an appropriate level. With too little control, the injury rate may be unacceptably high. With too much control, the cost of doing business is prohibitive.

Controls address two types of exposures: one where a known oxygen deficiency exists, the other in which an oxygen deficiency does not exist but there is a potential for its occurrence. A known oxygen deficiency could exist, for example, in a confined space in which sample results show <19.5% oxygen. Work planning would determine the controls needed to safely work in this space. Controls would include periodic atmospheric monitoring, self-contained breathing apparatus, ventilation and confined space permits. The premise for controlling the latter condition, a potential oxygen deficiency, is that the risk to workers should be no greater than risks in a general industry setting.

If exposure to reduced oxygen is stopped early enough, effects are reversible. If not, permanent central nervous system damage or death can result. Major effects hindering escape from the vicinity of an oxygen deficiency are disorientation and unconsciousness. For personnel actively working, unconsciousness occurs at ~13% oxygen. A person in the general area of a catastrophic release of an inert gas and not hurt by a pressure wave would be alerted to the escaping gas by the noise and, if a cryogenic gas, the cold. That person could out-walk the expanding inert-gas cloud by holding their breath and safely walking to the nearest exit.

The controls for potential oxygen deficiency are focused on the workers in the general area of the potential release, but not the immediate vicinity of the release point. The survival of individuals in the general area is highly probable because of the administrative and engineering controls, monitoring systems, and training.

For an unlikely scenario in which an individual is in the immediate vicinity of the equipment that failed at the time of failure, the affected individual would lose consciousness in seconds and probably not survive.

Training for workers includes the methods to become aware that a release of inert gas has occurred, escape methods and use of appropriate oxygen monitoring devices and escape packs. In addition to training on use of oxygen monitors and escape packs, ODH information is given in facility specific courses required of all employees and users. For example, see Collider Users Training, which covers ODH posting, the effects of oxygen deficiency, the ODH classification system, the ODH alarms and when and how to evacuate.

The following is a description of the graded approach methodology used to determine the controls necessary for areas having a potential for oxygen deficiency. It is recognized that these simplified methods cannot directly and quantitatively address the effects of the inert gas concentration gradients during transient release of the gas. The approach is to use a prescribed, simplified analysis to determine how an individual can have reasonable assurance that they are protected from a gas release. It treats the problem in a global way, by assuming homogenous mixing of the gas. For helium and lighter gases, this is not unreasonable. For heavier gasses, such as Tandem insulating gas, a spectrum of assumptions has been made bounding the cases for both homogenous mixing and no mixing. As already noted, individuals near the location of any release have higher likelihoods of injury or death. Thus a combination of the BNL SBMS ODH methods coupled with engineering judgment, assumptions on worker training, evacuation procedures and monitoring equipment are utilized in determining the controls needed to ensure an acceptably safe workplace.

The BNL SBMS models are used to determine the oxygen deficiency hazard (ODH) classification of a building. The SBMS is based on the Fermi ODH model. The Fermi Model is a prescribed method to determine the necessary level of hazard control for a building having the potential for oxygen deficiency. A graded approach is used to implement hazard controls as a function of the computed ODH fatality rate. The fatality rate is selected as the hazard index since death is the most important, non-reversible effect of exposure to oxygen deficiency. The average industrial fatality rate, $\sim 10^{-7}$/hr, is defined to be the fatality rate at which protective measures, other than training and postings are required.[82]

The fatality rate in the SBMS model is the product of two numbers. One quantity is the probability per hour of an initiating event causing an oxygen deficiency. The other quantity is found by estimating the minimum oxygen concentration during the transient, assuming instantaneous mixing of the air and inert gas in the building volume, and is represented by a factor between 0 and 1, see Figure 4.5.4.a. The computed fatality rate is then used to define the ODH class necessary to protect personnel.

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[82] T. Miller and P. Mazur, Oxygen Deficiency Hazards Associated with Liquefied Gas Systems: Derivation of a program of Controls, Am. Ind. Hyg. Assoc. J. 45(5):293-298(1984).

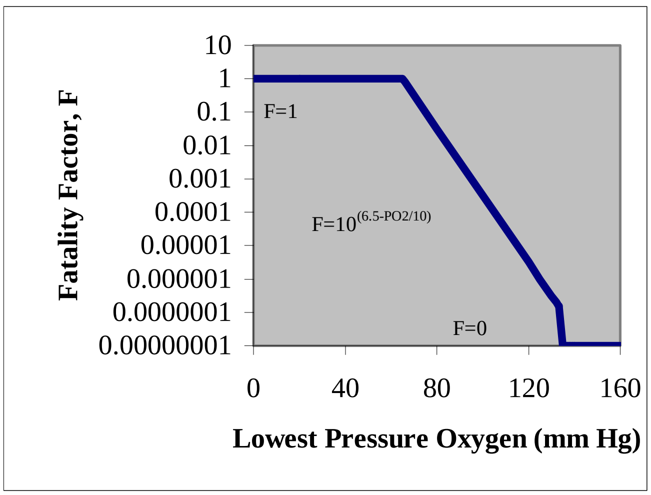
The ODH fatality rate is defined as:

$$\Phi = PF$$

where Φ = the ODH fatality rate per hour
P = the expected rate of the event per hour, i.e. initiator frequency
F = the fatality factor for the event, Figure 4.5.4.a

The value of P, the initiator frequency, is determined by using actual equipment failure rate data provided by Fermilab and by the Nuclear Regulatory Commission.

Figure 4.5.4.a. Graph of the Fatality Factor (logarithmic scale) versus the Computed Oxygen Partial Pressure.



The value of the fatality factor, F, is the probability that a fatality will result if a particular gas release occurs. Figure 4.5.4.a defines the relationship between the value of F and the computed oxygen partial pressure. The partial pressure is found by multiplying the mole fraction of oxygen in the building atmosphere by normal atmospheric pressure, 760 mm Hg. If the oxygen concentration is greater than 18%, about 137 mm Hg, then the value of F is defined to be zero. That is, all exposures above 18% are defined to be safe and do not contribute to fatality. If the oxygen concentration is 18%, then the value of F is defined to be 10^{-7}. At decreasing concentrations the value of F increases until, at some point, the probability of fatality becomes unity. That point is defined to be 8.8% oxygen, about 67 mm Hg, the concentration at which only one minute of consciousness is expected.

The computed value of Φ, the fatality rate, is then used to determine the ODH class of the building as follows:

ODH Class	Fatality Rate (per hour)
NA	$<10^{-9}$
0	$\geq 10^{-9}$ but $<10^{-7}$
1	$\geq 10^{-7}$ but $<10^{-5}$
2	$\geq 10^{-5}$ but $<10^{-3}$
3	$\geq 10^{-3}$ but $<10^{-1}$
4	$\geq 10^{-1}$

The oxygen concentration in the building during a release of inert gas is approximated by solving the following differential equations:

(a) If the exhaust fan is on and the spill rate of gas, R, is less than the exhaust fan capacity, Q:

$$V\frac{dC}{dt} = 0.21(Q - R) - QC$$

Where

V = building volume, ft^3
C = oxygen concentration, mole or volume fraction
t = time, minutes
Q = exhaust fan(s) flow rate, CFM
R = helium spill rate into building, CFM

(b) If the exhaust fan is off or if the gas spill rate, R, is greater than the exhaust fan capacity, Q:

$$V\frac{dC}{dt} = -RC$$

Areas of the facilities which have potential ODH hazards have been evaluated as described above. Oxygen concentration alarm points vary from 19.5% to 18%, depending upon the location. Alarms set points below 19.5% are acceptable because these alarms warn of accidents and not of planned, routine working conditions. The results for the affected areas of the facilities are summarized in the following sections.

Tandem

The Tandem Van de Graaff has an inventory of insulating gas (45% sulfur hexafluoride, 45% nitrogen and 10 % carbon dioxide) used to insulate the accelerator tanks. During operation, each tank contains 11,250 ft^3 of gas at 180 psig. This is ~35,000 lbm or 160,000 ft^3 at atmospheric pressure. The gas has a specific gravity of about 2.85 and a low diffusion rate in air. The hazards and controls in place for this gas are described and evaluated in a detailed calculation of the various potential release locations during gas transfer and normal operations.[83] The evaluation included the Tandem accelerator room, mechanical equipment room, electrical equipment room, target rooms, basement, TtB tunnel and the remote gas storage area located south of Building 703. The analyses included the potential effect of the heavier than air insulating gas by examining different cases of mixing of the gas with the surrounding air, from no mixing to complete mixing with the affected room volume. Recommended upgrades were

[83] L. Snydstrup, Calculation of Oxygen Deficiency Hazards for TVDG, Revision 0, November 5, 2001.

completed to assure that all locations within the Tandem and the gas storage area are classified no higher than ODH 0.

g-2 Experiment

This experiment is currently not used but when it ran ODH hazards were involved. Details of ODH and controls will be added to the SAD if this experiment is restarted.

RHIC

Mechanisms exist which could result in the release of helium into the Collider Tunnel, Service/Support Buildings housing valve boxes and associated cryogenic system equipment, and the buildings housing the refrigerators and helium compressors. As shown in Table 4.5.4.a, there also is the potential for the release of nitrogen into certain buildings. The quantity and release rate for each gas at each location is dependent upon many variables. Postulated worst-case, peak release rates are presented in Table 4.5.4.a, along with building volumes and ventilation rates. This table shows that the inert gas release rates can exceed the ventilation rates, thereby displacing air. Likewise, failure of the ventilation system will rapidly cause a hazardous level of air displacement. Table 4.5.4.a has notes that explain the major assumptions of the calculations.[84,85,86]

For the refrigerator building, an ODH 1 hazard class condition occurs after about 8 minutes with both ODH fans on and 5 minutes with one fan on. This is adequate time for an individual to egress following an alarm; however the building is conservatively classified as ODH 1.

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[84] R. Karol, Collider Building ODH Calculations – Revisited, April 18, 2000 (Revised 5/26/00).
[85] R. Karol, Building 1005E ODH Classification (Revised), December 26, 2001 (Revised May 6, 2002).
[86] R. Karol, Building 1006B Classification with Helium Reliquifier Running, September 20, 2002.

Some of the Service/Support buildings do not need controls; however, an ODH 0 is specified to uniformly apply ODH awareness and controls at the Collider.

The Helium Reliquifier components are located in buildings 1005E and 1006B. When this system is operating, calculations have shown that Building 1006B must be upgraded from ODH 0 to ODH 1 if only one exhaust fan is operable. Building 1005E requires two of the three exhaust fans to be operable to maintain an ODH 0 posting.

With the 80K Cooler on during Collider shutdown periods, the Tunnel and Service/Support Buildings are posted ODH 0 so that exhaust fans and oxygen sensors may be taken out of service without the need to keep track of the postings and to prevent confusion.

Helium spill tests, both at high and low release rates, were conducted to determine the helium gas temperature below which automatic ODH controls are required at the Collider.[87] It was concluded that the lowest temperature at which controls must be operable to protect personnel and maintain the ODH Hazard Class at the levels shown in Table 4.5.4.a is 50K. Above 50K, because of the decrease in helium density, the helium release rate would be less than 10% of the release rate at operating temperature of 4K. The areas need to be posted as soon as the helium system begins operation, but the oxygen sensors and ODH exhaust fans, which are part of the PASS, need only be operable when the helium temperature decreases to 50K.

[87] Relativistic Heavy Ion Collider Safety Assessment Document, October 1999. Chapter 4, Section A.6.

Table 4.5.4.a - ODH Classification for Collider Buildings

Building No.	**Name**	**Bldg. Vol (ft^3)**	**Total Fan CFM (# Fans)**	**Peak He (N_2) CFM**	**Frequency(1) (per hr)**	**ODH Class/Fatality Rate (Φ)** Case A(4)	Case B(5)
1005H	Compressor Building	250,000	100,000 (4 fans)	8,000(note 2) (1500)	$3x10^{-5}$	NA / note 6	NA / note 6
1005R	Refrigerator Building	240,000	50,000 (2 fans)	27,000(note 2)	$3x10^{-5}$	1 / note 7	1 / note 7
1005E	Reliquifier Building	30,000	10,000 (2 fans)	(5,000(note 2))	$5.9x10^{-3}$	0 / 2 x 10^{-8}/hr	0 / note 7
1001	Collider Tunnel - 1:00	310,000	60,000 (3 fans)	157,800(note 3)	$1.2x10^{-5}$	NA / note 8	0 / note 8
1003	Collider Tunnel - 3:00	300,000	60,000 (3 fans)	157,800(note 3)	$1.2x10^{-5}$	NA / $1x10^{-10}$	0 / $1.9x10^{-9}$
1005	Collider Tunnel - 5:00	390,000	60,000 (3 fans)	157,800(note 3)	$1.2x10^{-5}$	NA / note 8	0 / note 8
1007	Collider Tunnel - 7:00	400,000	60,000 (3 fans)	157,800(note 3)	$1.2x10^{-5}$	NA / note 8	0 / note 8
1009	Collider Tunnel - 9:00	320,000	60,000 (3 fans)	157,800(note 3)	$1.2x10^{-5}$	NA / note 8	0 / note 8
1011	Collider Tunnel - 11:00	300,000	60,000 (3 fans)	157,800(note 3)	$1.2x10^{-5}$	NA / $1x10^{-10}$	0 / $1.9x10^{-9}$
1002B	2:00 Support Building	70,000	32,000 (2 fans)	17,000	$3x10^{-6}$	NA / $1x10^{-10}$	0 / $1.1x10^{-8}$
1004B	4:00 Support Building	113,000	44,000 (2 fans)	17,000	$3x10^{-6}$	NA / $3x10^{-12}$	0 / $5.2x10^{-11}$
1006B	6:00 Support Building	85,000	32,000 (2 fans)	17,000 (12,000(note 2))	$3x10^{-6}$	NA / $4.1x10^{-11}$	0 / $2x10^{-9}$
1008B	8:00 Support Building	75,000	32,000 (2 fans)	17,000	$3x10^{-6}$	NA / $7.4x10^{-11}$	0 / $5.9x10^{-9}$
1010A	10:00 Support Building	110,000	22,000 (2 fans)	17,000	$3x10^{-6}$	NA / $6.1x10^{-11}$	0 / $8.6x10^{-10}$
1012A	12:00 Support Building	110,000	22,000 (2 fans)	17,000	$3x10^{-6}$	NA / $6.1x10^{-11}$	0 / $8.6x10^{-10}$

Notes:

(1) Frequency is given as the probability per hour that the bounding helium or nitrogen system failure occurs within the building.

(2) Conservatively assumed to be constant at these helium spill values for 1005H and 1005R and for nitrogen in 1005E and 1006B. The minimum ODH Class for the Compressor Building is conservatively set at ODH 0 due to the inventory of the helium present in the building and in order to simplify ODH controls.

(3) Peak helium spill rate obtained from AD/RHIC/RD-79, Estimation of Helium Discharge Rates for RHIC ODH Calculations, September 1995.

(4) Case A assumed all building fans operational. The minimum ODH Class for the Tunnel Sextants and the Support Buildings is conservatively set at ODH 0 due to the inventory of helium present in the buildings and in order to simplify ODH controls.

(5) Case B considers one fan failed. The ODH Class for all Support Buildings is based on the worst case to simplify ODH controls.

(6) For the Compressor Building, the oxygen concentration will only fall to a minimum of 18.8%. The minimum ODH Class for the Compressor Building is conservatively set at ODH 0 due to the inventory of the helium present in the building and in order to simplify ODH controls.

(7) For the Refrigerator Building and Reliquifier Building, the time to ODH 1 was determined ($\Phi = 10^{-7}$). See text for description.

(8) Tunnel Sextants 1003 and 1011 bound the conditions for all sextants because they have the smallest volumes.

4.5.5. Electrical Hazards

Chapter 3 and previous SAD revisions of C-AD owned accelerators, experiments and the Collider, describe in detail the numerous electrical devices, magnets, power supplies, vacuum system, RF systems, beam instrumentation and controls, that are employed at C-AD facilities including accelerators and experiments.

The sheer number of electrical devices and their conductors installed at accelerator and experimental facilities justifies recognizing electrical hazards as a major personnel hazard which requires detailed hazard controls. C-AD adheres to BNL SBMS, ES&H Standards 1.5.0 through 1.5.2 in order to mitigate electrical hazards. The hazards are described as follows:

AC Distribution

a) The primary AC distribution is at 13.8 kV. The feeds are underground to substations located at various sites. Transformers convert the 13.8 kV to 480 volts ac for subsequent distribution. Because of the very high hazard, the substations are fenced in with controlled access by the BNL Plant Engineering personnel. C-AD personnel do not normally have access to these areas.

b) Most secondary distribution is 480 V, 3 phase, 60 Hertz, ungrounded delta. This is used directly in many pieces of equipment, motors, pumps, power supplies, etc. It is further transformed to 220/120 V, 3 phase for lights, utility outlets and all general needs. Substations at Buildings 1005S and 1005H have grounded wye which is further transformed to 208/120 V. The RHIC tunnel lighting is 277 V which is fed from 480 V to 480/277 V isolation transformers to reduce the fault current magnitude. The 480/277 V neutral is grounded. There are two 4160 V substations at Building 1005H to power the helium compressors. Substations A-500, Q and 925 are also grounded wyes. The hazard at 480 V is not only from a 480 V shock, but also from the possible arc formation at a short circuit. The short circuit currents are extremely high and an arc can spray molten copper and other materials. The procedures followed on 480 V circuits include training, LOTO or key lockout, circuit voltage testing, and the use of proper personnel protective equipment.

High Voltage, Direct Current

a) Low Current - In many pieces of electronic equipment there are high voltage, low current, power supplies. While the current in some cases may present a direct shock hazard, in others it will be too low to cause a direct injury, but may lead to indirect injuries, such as, falls, bumps or other physical or electrical mishaps. Accelerator and experimental components are prominently marked for a high voltage hazard and may also be interlocked if a direct shock hazard exists. Experimenter's equipment use high voltage power supplies and each experimental set-up is reviewed by the ESRC before being energized.

b) High Current - In the range of 10-50 mA passing through the body significant physical harm may occur. The rf systems, as well as various pulsed magnets, kickers, and other devices, use potentially lethal power supplies. All such power supplies are properly marked; interlocks actuated on entry to the supply are hard wired to the power source; panel indicator lights show the power supply status; local-remote lockout switches are provided where more than one turn on location is used. Shorting devices are provided, manual or automatic, especially on capacitor storage devices.

High Current, Low Voltage

Many devices use high currents, up to several thousand amperes, at relatively low voltages. In most cases the shock hazards are low but a short circuit on the lines, just as in the 480 V ac case, can create a physical hazard. Proper warnings, enclosing of conductors and interlock devices are used.

RF Voltages

RF voltages in the many kilovolt level are present in the accelerating systems. Contact can result in shock and deep rf burns. The procedures as in the high voltage DC case are used.

4.5.6. Fire Hazards

The primary combustible loading in the injectors, accelerators, collider and experiments consists of magnets, power and control cables, and beam diagnostic equipment located throughout the complex. None of the materials is highly flammable, and with the possible exception of small amounts of control cable, all are expected to self-extinguish upon the de-energizing of electric power. Small amounts of flammable materials are routinely used in support of the accelerator operations and experiments.

Due to a system for diversion of radioactive liquid effluent to a hold-up pond, there are no environmental impacts due to release of contaminated water from the fire protection water system. Water sprayed on radioactive equipment may become slightly contaminated but would enter the sanitary system and be monitored before release. There are no significant amounts of combustible activated materials in the tunnels, rings, transport lines, intersection regions or beam lines and no significant radioactive particles would be present in smoke. Thus, there is no significant environmental hazard from a fire at the C-AD facilities.

At times, liquid hydrogen targets may be used in Building 912 for the experimental program. The danger of an over-pressure associated with a deflagration of hydrogen from such a target is about 17 lbs of TNT equivalent. The over-pressure wave is such that it will be lethal to anyone within a 30-foot radius. There is no full-time occupancy within this zone and equipment racks and monitoring stations are typically more than 30 feet away. These zones are maintained as low-occupancy areas. Experimenters and watch personnel may walk by or briefly work in the zone; typically, one or two people at a time. Flying debris will pose an additional threat. The peak over-pressures are likely to be significant to move large magnets nearby, collapse the target enclosure and collapse nearby experimental detectors. The nearby secondary beam dumps will likely remain standing.

The experiments at the Collider contain larger volumes of flammable gases in their detectors. Details of the hazards associated with these systems are presented in Chapter 4 of the original RHIC SAD. To mitigate these fire hazards the experimental detectors have mechanical and electrical interlocks, flow restrictors, designs to industry codes and standards, fusing, over and under flammable gas pressure protection, flammable gas detection, limits on flammable gas volumes, fire detection, alarm and suppression systems, control of combustible loading, ventilation systems, safety committee reviews, experimenter training for emergencies, automatic inert gas purging systems, control of ignition sources, and enhanced work planning.

4.5.7. Hazard Controls

The purpose of this section is to briefly summarize the various system features and administrative programs that help to control hazards or the minimize risk of various hazards.

Radiation Protection

The significant hazard at the C-AD facilities is ionizing radiation, and operations are planned to be within DOE dose guidelines. The Department uses a graded system of controls such as shields, fences or barriers, locked gates, interlocks and procedures to match access restrictions with potential radiation hazards that satisfies both the BNL and DOE requirements.

Although the Laboratory site is a limited access site, service personnel from off-site or BNL non-radiation workers may work near C-AD facilities or may traverse the complex. The BNL policy is to administratively restrict the dose to 25 mrem per year to such personnel. The C-A Department adheres to this policy by using shielding, radiation monitoring devices that prevent radiation levels from exceeding set points, radiation work permits, work planning and RS LOTO.

Shielding for C-AD facilities is also designed to permit access by appropriately trained personnel to areas adjacent to the beam enclosures even with nominal inadvertent beam loss. In locations where the losses are expected to be greater, such as outside the shielding near collimators or the beam stops, physical barriers such as fences are used to control access and minimize exposures. Depending on the area classification, these barriers may be locked and/or posted as Controlled Area, Radiation Area or High Radiation Area.

There is the potential of significant residual activity in several locations, which are targets, collimators, injection regions, and beam dumps. To work near these locations, movable shielding may be brought into place using the remote capabilities such as a crane or a fork truck. This minimizes the potential integrated person-dose for work done within the beam enclosure.

Permanent Shielding and ALARA Dose

Shielding will be used to reduce radiation levels in occupied areas to acceptable levels. The C-A Department's shielding policy is given in Appendix 3. Potential access points into areas where personnel are prohibited during operations will be controlled by the Access Control System, ACS and PASS.

Shielding design analyses were performed for all sections of C-AD facilities, and ALARA was integrated into the overall facility designs. Soon after beam is available, studies are conducted in order to verify the design and to optimize shielding, as needed, to help achieve an ALARA dose to facility personnel and facility users. Extensive radiation surveys of normal operations, as well as low-intensity simulated, credible beam faults, are conducted as required during commissioning and initial operations of new portions of the facility or experiments. These surveys provide assurance and verification of the adequacy of the shielding and access controls. It is noted that the permanent shielding and access controls are configured to support the BNL Radiation Control Manual dose limit requirements, and are further enhanced to support the BNL Radiation Control Manual ALARA considerations.

The shield was planned with ALARA in mind such that, during normal operations, the dose rate on accessible outside surfaces of the shield is planned to be less than 0.25 mrem/h in areas under access control. Areas under access control are all designated Controlled Areas or radiological areas as defined in the BNL Radiation Control Manual. The design of 0.25 mrem/hr is a guideline based on the actual ALARA design objective of less than 500 mrem per year. That is, assuming 100% occupancy at the shield face, a 2000-hour per year residence time yields an acceptable ALARA design objective of 500 mrem. The 500 mrem per year ALARA design objective is one half the design objective stated in 10CFR835 § 835.1002 (b).

Since there are many ways to control access and residence time by area designation, training, signage and work planning and since there is a decrease of dose rate with distance from the shield face, significantly higher shield face dose rates are often acceptable. Therefore, shields are evaluated in terms of the guideline of 0.25 mrem/h, and instances where higher values may be acceptable have postings to indicate where area designations play a major role in minimizing radiation exposures.

Permanent Shielding Materials

The permanent bulk shielding materials for the C-AD facilities are primarily materials used at all existing accelerator facilities. For example, concrete, iron and earth provide protection for personnel outside the beam tunnels, target stations and beam intersecting regions. In addition, in order to satisfy the BNL capping requirements, the berms which surround significant beam loss locations are covered with caps to prevent leaching of soil activation products, tritium and sodium-22, from contaminating the groundwater. In addition to the materials mentioned above, paraffin, borated paraffin, polyethylene, borated polyethylene, lead and depleted uranium[88] may be used for local shielding and in special circumstances. Shielding configuration is closely controlled and may not be changed without review and approval of the C-A Radiation Safety Committee (RSC).

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[88] Implementation Plan and Basis for Interim Operation (w/PHA) AGS Uranium Shield Block and Experiment 877 Uranium Calorimeters.

Radiation Detection and Radiation Interlocks

At locations external and/or adjacent to beam enclosures where unlikely but possible beam loss may occur, the use of hard-wired, fail-safe interlocking radiation monitors are used. This technique is standard practice at DOE accelerator facilities to maintain radiological-area classification compliance by providing a robust and rapid beam inhibit if any monitor exceeds a preset interlock limit. These radiation monitors are part of the QA level A1 safety-significant access-control-system for personnel protection.

Interlocking radiation monitors are calibrated annually. These radiation monitors have been dubbed Chipmunks. They are tissue-equivalent ionization chambers that measure dose equivalent rate, in mrem per hour, from pulsed, mixed-field neutron and gamma radiation. Chipmunks are used as area-radiation monitors for personnel protection and are located throughout the facility in accessible areas. Chipmunks are used to interlock the ion beams should radiation levels exceed limits defined by the C-A Radiation Safety Committee. The operation of Chipmunks with interlocking capability is fail-safe. Loss of power results in beam off for interlocked Chipmunks, and/or an alarm in the Main Control Room in Building 911A, a control room that is manned around-the-clock during operations. Additionally, the Chipmunk uses a built-in keep-alive radiation source to monitor for failures. Such a failure will trigger an alarm in the Main Control Room and/or an interlock when appropriate.

The interlock system is hard-wired and uses relay logic and PLCs to activate or deactivate a device such as a beam stop or magnet power supply to prevent beam from entering the fault area when a fault condition is detected. The PLC systems are monitored by an independent computer, and the fault condition is logged.

Fixed-location area-radiation monitors such as Chipmunks also provide real-time dose information at various locations along the beam path and in the target, support and experimental buildings. This dose rate data is logged every few minutes and stored on computers. General locations are initially selected for the real-time monitors; exact locations are determined based on beam-loss tests conducted during the facility commissioning phase and on subsequent radiation surveys during operation. Final area radiation monitoring instrument locations are approved by the C-A Radiation Safety Committee.

Additional area monitors may be used to assess the long-term integrated dose in areas accessible to the public and other individuals not wearing personnel dosimeters. Thermo-luminescent dosimeters (TLDs) identical to those worn by radiation workers are mounted in locations in accordance with the BNL Radiological Controls Division procedures for this purpose. The dose recorded by these TLDs is indicative of the exposure of a person spending full time at that location. Neutron dosimeters, if their use is indicated for this purpose, will be attached to phantoms to simulate use by personnel.

Control of Radioactive Materials and Sources

When the beam is turned off, the remaining radiation hazard comes from activated material and sources. Activated material may be a direct radiation hazard, and may have removable contamination. All known or potentially activated items will be treated as radioactive material and handled in accordance with BNL Radiation Control Manual requirements. Unlabeled radioactive material that is accessible to personnel is placed in appropriately posted radiological area. Suspect radioactive material is surveyed by a qualified RCT before release and then controlled in accordance with the survey results. Process knowledge may also be used to certify items being removed from radiological areas as being free of radioactivity. Known radioactive materials are appropriately labeled before removal from an area that is posted and controlled. Radioactive items with removable contamination on accessible surfaces are packaged before removal from posted radiological areas. Workers whose job assignment involves working with radioactive materials receive documented training as radiological workers. Radioactive sources below accountable-activity-limits are treated as radioactive material. Accountable sealed radioactive sources are controlled, labeled and handled in accordance with the BNL Radiation Control Manual and the C-A Operations Procedure Manual. Accountable sealed radioactive sources that are in regular use are inventoried and leak-tested every six months.

Portable Radiation Monitors

Portable radiation detection instruments are used by Radiological Control Technicians (RCTs) and, potentially, other trained and approved C-A personnel, to measure the radiation fields in occupied areas during commissioning and periodically during normal operations. These measurements will be used to establish and confirm area radiological postings. Instruments used for this purpose will be appropriate for the type and energy of the expected radiation, and will be calibrated in accordance with requirements.

Frisking Instruments

Experience at the C-AD accelerators and experiments have shown that contamination is not a significant problem at our facilities. However, routine contamination surveys are conducted to verify that contamination is not a problem. Instruments used to frisk personnel who are exiting posted areas that might contain removable contamination are used as appropriate.

Personnel Dosimetry

All radiation workers wear appropriate TLDs and self-reading dosimeters as required by the BNL Radiation Control Manual while working in areas posted for radiation hazards. Dosimeters are exchanged on a regular basis and processed by a DOELAP-accredited laboratory. Records of the doses recorded by these dosimeters are maintained, and these records are available to the monitored individuals.

Access Controls Systems

The radiation security system design for access controls at C-A facilities has operation for over 43 years. The C-A Department has classified the security system as

QA level A1 according to the C-A QA plan, but the Department allows certain components to have a lower classification because failure is to a safe state or critical parts are redundant. The Access Controls Group installs industrial grade components only. This Group labels parts that pass incoming tests as A1 or A2 and places labeled parts in controlled storage areas. The Group maintains documentation for these acceptance tests.

The basic design principles of the access control system are:

- either the beam is disabled or the related security area is secured
- only wires, switches, relays, PLCs and active fail-safe devices, such as chipmunks, are used in the critical circuits of the system
- the de-energized state of the relay is the interlock status; that is, the system is fail-safe
- areas where radiation levels can be greater than 50 rem/h require redundancy in disabling the beam and in securing the radiation area
- if a beam fails to be disabled as required by the state of its related security area, then the upstream beam would be disabled; that is, the system has backup or reach-back

Very High Radiation Areas are those areas that enclose primary beam. Very High Radiation Area hardware requirements comply with the BNL Radiation Control Manual. The C-A Radiation Safety Committee requires: 1) locked gates with two independent interlock systems, 2) fail safe and redundant radiation monitors or other sensing devices, 3) indicators of status at the facility in the Main Control Room, 4) warning of status change, and 5) emergency stop devices within potential Very High Radiation Areas.

The C-A Radiation Safety Committee reviews interlock systems for compliance with requirements in the BNL Radiation Control Manual, Standards Based Management System requirements and C-A Operations Procedure Manual procedures. A

Representative of the BNL Radiological Controls Division is a member of the C-A Radiation Safety Committee. The C-A Radiation Safety Committee defines the design objectives of the security system and approves the logic diagrams for relay-based circuits and state tables for PLC-based circuits. Cognizant engineers sign-off on wiring diagrams and the C-A Chief Electrical Engineer approves each diagram. The C-A Access Controls Group maintains design documentation.

The Access Controls Group conducts a complete functional check of all security system components at an interval required by the BNL Radiological Control Manual. In the checkout, the Access Controls Group checks the status of each door-switch on a gate, and each crash switch in the circuit. They check the interlocks and the off conditions for all security-related power-supplies to magnets, magnets that may act as beam switches, and for all security-related beam-stops. They check every component in a security circuit. As they test, they fill-out, initial and date the security system test-sheets obtained from the C-A Operations Procedure Manual. Test records are maintained as required by the C-A Operations Procedure Manual.

Control and Use of Hazardous Materials

The BNL Chemical Management System is designed to ensure that workers are informed about the chemical hazards in their workplace. The Chemical Management System is maintained to comply with OSHA and EPA regulations concerning hazardous chemical communications. This program includes provisions for policy, training, monitoring exposure limits, handling, storing, and labeling and equipment design, as they apply to hazardous materials. Inclusive in the hazardous material protection program will be: procurement, usage, storing, inventory, access to the hazardous materials, as well as housekeeping and chemical hygiene inspections of C-AD facilities. All BNL general employees receive appropriate general Hazard Communication training. Standards for general hazardous materials communication and for special materials, such as beryllium, mercury and biological materials are specified by the BNL Standards Based Management System. Training to these standards is provided, and the training program records are maintained on the BNL BTMS. C-AD staff and experimenters working in areas with a potential for exposure to hazardous chemicals receive appropriate job-specific training at the time of initial assignment and whenever a new hazard is introduced into the work area. A comprehensive listing of all Materials Safety Data Sheets for the chemicals used at the BNL site is available on the BNL web or equivalent. The system of work controls, which is part of the BNL Integrated Safety Management System, requires enhanced work planning for work with certain hazardous materials; for example, beryllium. The enhanced work planning ensures that adequate hazard controls and completion of required training are in place before work with hazardous materials begins.

The use of flammable liquids is minimal. For example, the anticipated use at NSRL is less that one quart in each laboratory space as a solvent. Any use of flammable liquids follows BNL ES&H Standards / SBMS requirements.

Electrical Safety

The requirements for electrical safety are given in detail in the BNL Standards Based Management System and the C-A Operations Procedures Manual. Electrical bus work is covered to reduce/prevent electrical hazards in the power supply areas. In beam enclosure areas, exposed conductors will not be present and magnet buss will be covered. The Main Control Room will lock out all power supplies that power devices inside a beam enclosure whenever the area is placed in Restricted Access mode. In Controlled Access mode, even though the magnets will not be powered, the power supplies will not be locked out. Workers are trained to assume that magnets are powered in all cases and to treat them accordingly. In cases where workers are required to work on or near a specific magnet during Controlled Access or Restricted Access, the magnet power supply will be locked out and tagged out by the worker.

In some cases, it will be necessary to work near magnetic elements while powered. Appropriate control over access during this mode is maintained by the Operations Coordinator. Work planning, Working Hot Permits and training requirements for entrants under these circumstances address concerns for inadvertent contact with powered conductors and exposure to magnetic fields.

Lockout/Tagout Program

Lockout/tagout procedures are specified in the C-A Operations Procedure Manual. All workers will be required to train in lockout/tagout procedures at a level consistent with their position. Where electrical hazards could be present to C-A personnel working in an area, lockout/tagout procedures are implemented only by trained and authorized personnel.

Safety Reviews and Committees

Standing safety committees are utilized throughout design, construction, commissioning and operation to focus expertise on safety, environmental protection, pollution prevention and to help maintain configuration control. See Chapter 3 for details of each committee's authority and responsibility.

Training

Worker training and qualification is an important part of the overall ESH plan for C-A Department. Training and qualification of workers is described in the Operations Procedures Manual and the required training for individuals is defined in the Brookhaven Training Management System (BTMS). All staff personnel and experimenters require an appropriate level of training to ensure their familiarity with possible hazards and emergency conditions.

Workers are trained in radiation and conventional safety procedures at a level consistent with their positions. The number and type of training sessions/modules is assigned using a graded approach commensurate with the staff members' responsibilities, work areas, level of access, etc. An up-to-date record of worker training will be kept in the BTMS database. Radiation worker access will only be allowed if adequate training is documented, except in cases of emergency. Training procedures and course documentation will be reviewed and updated periodically.

Personal Protective Equipment

Special clothing is used to protect workers who are exposed to the various electrical hazards and hazardous materials, including chemicals and radiation. The clothing for a particular application is selected considering the expected hazards; a variety of types of clothing is needed to meet all hazards. There are no predicted hazards that are unique to C-A facilities, and experience is applied to ensure the adequacy of protective clothing in a particular application.

Respiratory protection is provided for workers who might otherwise be exposed to unacceptable levels of airborne hazardous materials, including chemicals, oxygen deficient atmospheres and radioactive materials. Respiratory protection is selected, used and maintained per OSHA 29CFR1910.134 and BNL Respiratory Protection Procedures.

4.5.8. Significant Environmental Aspects and Impacts

In support of Brookhaven National Laboratory's broad mission of providing excellent science and advanced technology in a safe, environmentally responsible manner, the Collider-Accelerator Department is committed to excellence in environmental responsibility and safety in all C-A Department operations.

To provide excellent science and advanced technology in a safe and environmentally responsible manner the Collider-Accelerator has, over the past 15 years, continuously reviewed the aspects of its operations in an effort to identify and accomplish waste minimization and pollution prevention opportunities. This process began in 1988 with the development of formal environmental design guides and a design review process. More recently, this effort has resulted in a further formalization of its processes under the guidelines of ISO 14001, the BNL ISO 14001 "Plus" Environmental Management System Manual, and SBMS subject areas governing ISO 14001 implementation. The BNL EMS program emphasizes compliance, pollution prevention and community outreach. Based on the aspect identification and analysis process in the Subject Area, Identification of Significant Environmental Aspects and Impacts, the following aspects are significant to the C-AD activities:

- regulated industrial waste
- hazardous waste
- radioactive waste
- atmospheric discharge
- liquid effluents
- storage/use of chemicals or radioactive material
- soil activation
- PCBs
- environmental noise
- water consumption
- power consumption

The environmental policy as set forth by Brookhaven National Laboratory in the Environmental Stewardship Policy is the foundation on which the C-A Department manages significant environmental aspects and impacts. The formal management program is called the C-A Environmental Management System. The Environmental Management System consists of the following elements, the details of which may be found in the C-A Operations Procedure Manual:[89]

- environmental policy
- planning
- environmental aspects and impacts
- system for determining legal and other requirements
- system for defining objectives and targets
- environmental management programs
- implementation and operation
- structure and responsibility
- training, awareness, and competence
- communication
- environmental management system documentation
- document control
- operational control
- emergency preparedness and response
- checking and corrective action
- monitoring and measurement

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[89] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch01/01-10-02.PDF Environmental Management Program Description

- nonconformance and corrective and preventive action
- records management
- environmental management system audit
- management review

The requirement for a process evaluation is listed in C-A OPM Chapter 13. Waste streams are reviewed by the C-AD Environmental Compliance Representative (ECR) and a process evaluation denoting all material inputs and outputs for the each process is on file for existing processes. A new process evaluation is performed for each new, significant process before commissioning the new facility for operations.

4.5.9. Hazard Reduction Associated With Waste Generation and Handling

Hazards associated with handling, packaging, treating and disposing of wastes generated during operation and modification of the facility are reduced when the generation of these wastes is minimized via pollution prevention (P2) techniques. The BNL approach to P2 associated with the operation and modification of accelerators and experiments is to address it during the design and construction phase. The objective is to minimize or eliminate the anticipated costs associated with hazardous and mixed waste generation as well as the treatment and disposal of wastes and the consumption of resources in all facility life cycle phases: construction, operation, closure and decommissioning. Dollars spent during the design phases will provide for significantly reduced total costs over the life of the facility thus making more funds available for science. The following are the main objectives of the BNL P2 program:

- minimize the amount of hazardous, radioactive and mixed wastes that are generated
- minimize the cost of waste management
- comply with federal, state and local laws, executive orders and DOE orders

The Collider-Accelerator Department has implemented a P2 program as part of its commitment to comply with the Environmental Management System and ISO 14001. C-AD facilities have been registered to the ISO standard by a third party registrar since CY 2000. A number of lessons learned in this area from other BNL operations are incorporated into C-A operations. Modifications to C-A operations have helped minimize hazards and costs associated with the generation of waste streams.

4.5.10. Fire Detection, Egress, Suppression and Response

The basis of design for fire detection, egress, suppression and response has been determined in the individual fire hazard analysis (FHA). FHAs are on the C-AD web. C-AD facilities comply with DOE fire protection guidelines as well as NFPAs. The system is integrated with the site-wide system and is comprised of an automatic fire detection and suppression system that includes automatic fire suppression and rapid response capability coverage by the BNL Fire Department. Sprinklers are provided at the building ceiling or roof levels, intermediate levels and at or within enclosures, as required. Because of the low flammability of the magnets, power and control cables and beam diagnostic equipment in the tunnels and rings, they do not have automatic fire suppression systems, except for certain areas. They do have fire standpipes. Manual and automatic fire detection and alarm initiation devices are installed throughout the facility.

Where needed, smoke and/or heat detection devices are supplemented with pressure sensitive sensors, flammable gas detectors or other advanced detection devices such as high sensitivity smoke detection, HSSD. The appropriate portable fire extinguishers are provided for manual fire fighting efforts by trained staff. Fire alarms are alarmed at the BNL Fire Department, Building 599, and at BNL Police Headquarters, Building 50, thus providing continuous coverage for rapid fire response. This will put additional professional fire fighting resources into action within a short period. Roadways around the facility help protect it from surrounding wildfires. The building roofs are non-combustible metal and do not ignite from burning ash from brush fires.

The means of egress for occupancies is in accordance with NFPA 101. Enclosure exhaust fans are located at tunnels and rings for rapid smoke removal.

4.5.11. Routine Credible Failures

Routine credible challenges to controls associated with worker and experimenter protection and with environmental protection are further detailed in Appendix 2.

Beam losses in C-A accelerators and experimental enclosures are sufficiently attenuated by the bulk shielding for expected routine operation. Adequate shielding is provided to meet requirements established by the Laboratory for permissible exposure to radiation workers, non-radiation trained workers and members of the public during normal machine operations. Present shielding designs reduce all normal radiation levels to well below the DOE ALARA guidelines.

Exposure to nearby facilities is less than 25 mrem per year and only a small fraction of 5 mrem per year at the site boundary, which are the Laboratory guidelines for radiation exposure for nearby facilities and the site boundary, respectively. Radiation exposure to maintenance workers is reduced through the design of equipment to simplify maintenance and the selection of materials to minimize failures. In particular, equipment at high loss points such as targets, beam dumps, collimators, beam injection and beam extraction points receive detailed examination to assure that radiation exposure received in passing and during the maintenance of these components is kept as low as reasonably achievable. Through such reviews, it is reasonable to expect that maintenance activities be controlled to maintain radiation exposures well within the DOE annual limits, limits that are 5 to 20 times higher than the ALARA guidelines.

There are no significant quantities of dispersible gaseous or liquid radioactive materials, except for the radioactivity induced in magnet cooling water. In primary beam-line areas where the cooling water might escape confinement, e.g., a hose break, water detection mats underneath the magnets alarm and alert the watch personnel. Watch personnel are trained to confine, clean up and report water spills to management. Experience indicates that up to several hundred gallons may leak onto the concrete floor. The concrete floors are impermeable. Spilled water is sampled before release to the appropriate waste stream or is allowed to safely evaporate in place. No off-site threats to the public are present.

4.5.12. Maximum Credible Accidents

This section describes the bounding analysis scenarios for credible C-A facility accidents.

Maximum Credible Beam Faults

Linac, Tandem, Booster, AGS and Fixed Target Experiments

Not all protons will be stopped at the targets or at well-defined loss locations; some may be lost during transport. The design goal of no more than 20 mrem per full-fault event in an uncontrolled area is met by the proper design of shielding and radiation monitoring and interlocking systems. Typically, the shielding on the transport lines allow these areas to be designated no more than a "High Radiation Area" during a full-fault event; that is, maximum dose rate during a fault is less than 5000 mrem in 1 hour. These areas are further protected by interlocking radiation monitors which turn off the radiation source within 9 seconds of detecting a fault condition. Thus, the design guideline of no more than 20 mrem per event in an uncontrolled area is satisfied through a combination of shielding, postings, radiation monitors and beam interlocks.

Based on archival operating records, beam faults occur when magnet power fails, beam tuning is improperly controlled or when beam-line components are misaligned and placed into the beam path. Operators in the Main Control Room detect the problem immediately upon radiation alarm trips and from the resultant interlocks which turn the beam off. Operators are trained to investigate these events according to written procedures, correct the problem if appropriate, record the event for management review, and to discontinue operations if appropriate. Given the length of these events, 9 seconds or less, and the frequency of these events, several times during an annual running period, off-site radiation impact is negligible.

Experience at C-AD shows that use of 1) thick shielding, 2) fences and barriers at the berm and other areas, 3) ALARA beam tuning procedures, 4) radiation alarms in MCR and procedures that call for response to radiation alarms are sufficient to protect personnel in locations not directly monitored by radiation monitors or “chipmunks”.

Based on the system for formal design review by C-AD Committees, formal BNL and C-AD training programs, formal C-AD operations procedures, formal C-AD quality assurance programs for equipment, and the extensive use of shielding and access controls, the probability of a "catastrophic" radiation exposure is extremely improbable, that is, the probability for this consequence cannot be distinguished from zero.

The use of radiation area monitors and interlocks to prevent high fault dose rates from occurring maintains exposures well within the limits established by DOE. Thus, the probability of a significant inadvertent radiation exposure is remote and is not likely to occur within the life cycle of the C-AD facilities. Routine maintenance and operations activities are well controlled and will not result in exceeding the annual radiation limits established by DOE.

RHIC

The RHIC Beam Loss Scenario assumes that an uncontrolled loss of a beam at full energy is possible at a location other than at the intended loss point, the Beam Stops at 10 o'clock. In the case of a bounding Collider fault with the ASE limited intensity proton beam, it is assumed that, for most locations in each ring, half the beam, the equivalent of 1.14×10^{13} 250 GeV protons, is lost at a point and the other half distributed over an extended length of magnets. The entire beam could be lost at an aperture-defining location including the high β quadruples. At the superconducting Tevetron at Fermi National Laboratory the entire full energy beam has been lost twice in approximately 10 years of running, but in both cases the loss was distributed over a long portion of the machine. The maximum credible loss defined here is therefore conservative. The maximum dose from a bounding fault to an individual standing at a typical location on the berm is estimated to be 57 mrem. This is within the 100 mrem regulatory dose limit for untrained individuals in uncontrolled areas. This fault is higher than the 20 mrem limit for all other C-A facilities because the entire stored beam in the Collider is lost at once, whereas at facilities other than the Collider, the beam is interlocked off within 9 seconds. During the commissioning and the first year of operation, the RHIC beam intensity was slowly increased, so that uncertainties in calculations of the dose potential could be determined by a series of fault studies. These fault studies were documented by Stevens[90]. Thus the maximum credible Collider fault has no adverse impact.

[90] A. J. Stevens, C-AD/ES&F Technical Note No. 156, Summary of Fault Study Results at RHIC, July 12, 2000.

Maximum Credible Fire

The objectives of presenting no threats to the public health and welfare or undue hazards to life from fire are satisfied. The designs of all C-A facilities comply with the "Life Safety Code" (NFPA 101) and with the specific requirements of the Occupational Safety and Health Standards (CFR29, Part 1910) applicable to exits and fire protection.

Welding gases and flammable/explosive gases used in experiments are used and stored according to NFPA codes and standards applicable to experimental installations. Gases are stored in compressed gas cylinders that meet DOT specifications. Large quantities of gas are forbidden in experimental areas, and experimenters are limited to using 100 to 200 lb cylinders during running periods. There are no off-site threats to the public should a cylinder fail.

Experiments are designed with an "improved risk" level of fire protection. The design requirements that were used are found in: 1) DOE Order 420.1, Facility Safety and 2) DOE Order 6430.1A, General Design Criteria. Experiments are fitted with fire detectors and fire protection systems where appropriate. Fires at experiments are expected to be extinguished by these protective systems. Combustible loading of the primary beam lines consists of magnets, power cables, control cables and beam diagnostic equipment. None of the materials are highly flammable, and with the possible exception of small amounts of control cable, all are expected to self extinguish upon de-energizing of electric power. Induced radioactivity is deeply entrapped in magnets and concrete shielding and is not dispersible in a fire. There are no off-site threats to the public from a fire.

The personnel risks associated with the fire hazard are acceptable considering the type of building construction, the available exits, the fire detection systems, the fire alarm systems and the relative fire-safety of the components and wiring. Emergency power and lighting is available in accordance with fire industry standards.

Travel distances to exits in the C-AD facilities do not present a problem. In structures of low or ordinary hazard and in structures used for general or special industrial occupancy, NFPA 101 permits travel distances up to 120 m to the nearest exit if the following provisions are provided in full:

- application is limited to one-story buildings only
- interior finish is limited to class a or b materials per NFPA definitions
- emergency lighting is provided
- automatic sprinklers are provided in accordance with NFPA 101
- extinguishing system is supervised

Smoke and heat venting by engineered means or by building configuration are provided to ensure that personnel are not overtaken by spread of fire or smoke within 1.8 m of floor level before they have time to reach exits.

DOE has established limits of $1,000,000 for a Maximum Possible Loss and $250,000 for a Maximum Credible Loss mandating the installation of automatic suppression systems in locations where those limits are exceeded. C-A facility designs meet these criteria.

The results of Fire Hazard Analyses for each major C-A facility are documented in the Appendices. These FHAs include the Maximum Possible Loss and Maximum Credible Loss for each facility.

Maximum Credible Electrical Accident

The electrical systems and equipment have been in use at C-A facilities for many years. This statement does not minimize the inherent dangers; rather, it indicates that the technical personnel are experienced on accelerator circuits and devices. Additionally, they are qualified to work on these systems. Every engineer, technician and electrician that is expected to work on the facility equipment is adequately trained. The training includes an awareness of potential hazards and knowledge of appropriate safety procedures and emergency response plans. Training is documented and a list of authorized personnel is kept on a network electronic database (BTMS) and available to supervisors.

The C-A staff is familiar with the types of electrical hazards that relate to the accelerators and experimental areas. All reasonable safety features are installed in and on the electrical equipment. The groups that maintain, repair, test and operate the equipment have the knowledge, tools and experience to perform safely. Work planning, which includes electrical safety procedures, working hot permits and job safety analyses, is done to adhere to the safe practices mandated by OSHA and the BNL SBMS Subject Area on Electrical Safety. Periodic retraining improves the safety margin. Thus, the potential risk for a serious electrical shock is minimized to levels currently accepted throughout the industry.

4.5.13. Risk Assessment to Workers, the Public and the Environment

Radiation Risks

The routine radiation dose to workers is well below the DOE regulatory limits of 10CFR835. The range of doses received by C-A radiation workers in CY2000, which was a typical recent year with full high-energy and nuclear physics programs, is shown in Figure 4.5.13.a. Experience shows the average exposure of C-A radiation workers is about 30 mrem per year. The dose to an average C-A radiation worker is only a small fraction of the regulatory limit, and the increase in fatal cancer risk after a lifetime of radiation work, 50 years, is insignificant, 0.06%[91] compared to the naturally occurring fatal cancer rate of nearly 20%. Additionally, due to increased emphasis on the nuclear physics program and due to improvements in high-intensity beam steering and confinement, the radiation burden for the C-A worker has been declining for decades. See Figure 4.5.13.b for the decline since the early 1990s. The risks to the public are an extremely small fraction of worker risk.

Worker doses, even including the maximum credible beam fault dose on a frequent basis, would not cause deterministic effects such as burns or tissue damage unless an individual were in the beam enclosure during operations. The Access Control System, which is categorized as Safety-Significant, assures that such irradiations are not credible.

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[91] This assumes a risk coefficient of $4x10^{-4}$ per rem for workers from NCRP Report No. 115, Risk Estimates for Radiation Protection (p. 112) and a 50-year career at 30 mrem per year.

Figure 4.5.13.a Range of Radiation Worker Dose at C-A Department for CY2000

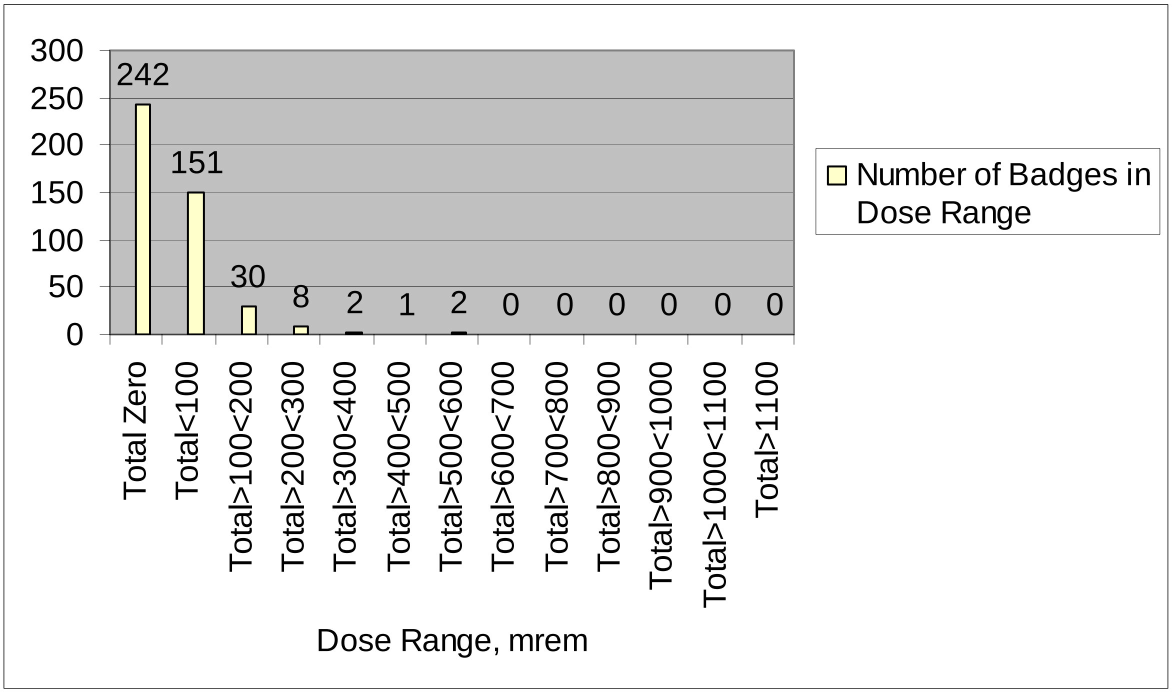
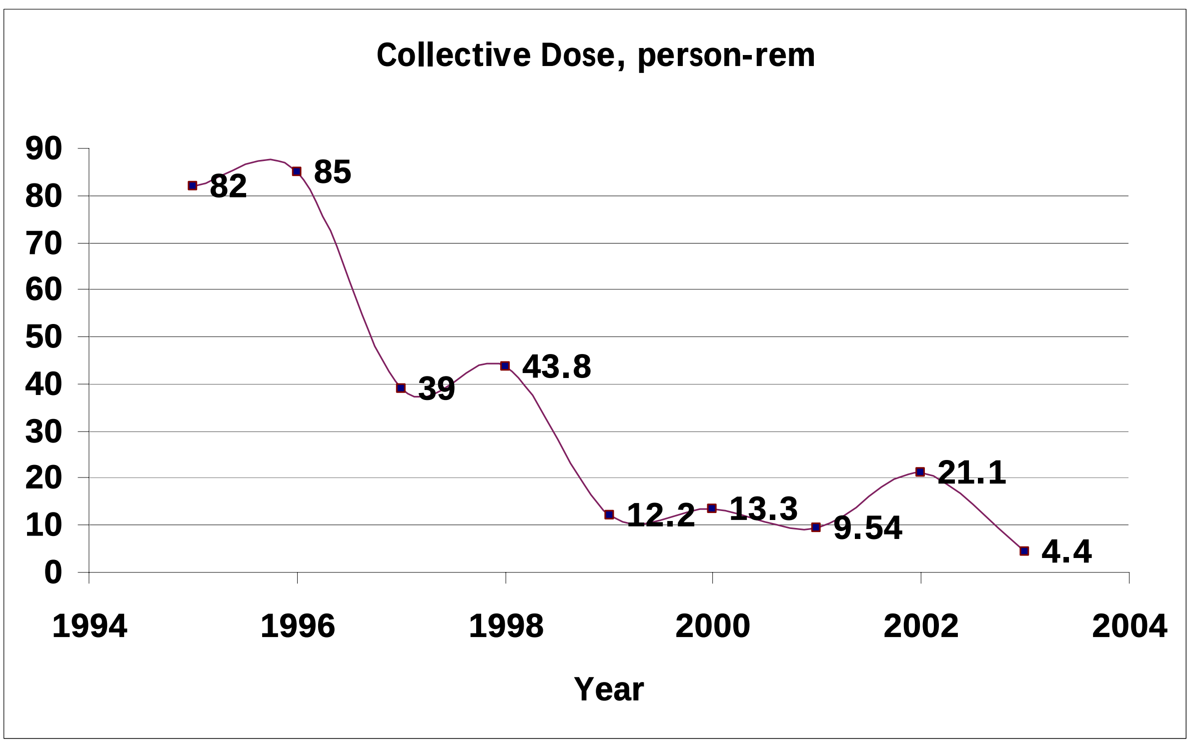


Figure 4.5.13.b Decline in Radiation Worker Dose at C-A Department



Infectious Microorganism Risks

These risks are present at the NSRL. Biological safety cabinets (BSCs) are the primary means of containment developed for working safely with infectious microorganisms. This equipment, located in cell rooms C1 and C2 of the Support Laboratories in Building 958, is appropriate when any work is done with human-derived blood, body fluids or tissues where the presence of an infectious agent may be unknown. Class II Type A BSCs provide personnel, environmental and product protection. Airflow is drawn around the operator into the front grille of the cabinet, which provides personnel protection. In addition, the downward laminar flow of HEPA-filtered air provides product protection by minimizing the chance of cross-contamination along the work surface of the cabinet. Because cabinet air exhaust is passed through a certified exhaust HEPA filter, it is contaminant-free (environmental protection), and may be re-circulated back into the laboratory (Type A), which is the type of BSC employed at cell rooms. CDC standards for BSC testing require an annual test, which includes annual efficiency tests as well as a smoke test and air velocity test. The BSC must maintain a minimum calculated or measured average inflow velocity of at least 75 linear feet per minute at the face opening of the cabinet.

Environmental Risks from Radiation

The only credible risk to the environment is groundwater contamination. This may be caused by a spill of radioactive cooling water from a failed pipe or hose or by an activated soil cap failure, which would allow rainwater to leach the contamination into the aquifer.

An extensive groundwater-monitoring program has been instituted to verify the effectiveness of soil caps and soil-cap maintenance procedures. In accordance with DOE Order 5400.1, General Environmental Protection, groundwater quality down gradient of actual or potential soil activation areas is verified by periodic sampling of groundwater surveillance wells. Groundwater samples are tested for tritium and sodium-22 to verify that the soil caps are effectively preventing rainwater infiltration of activated soil shielding. Sampling frequency for the wells is defined in the annual BNL Environmental Monitoring Plan. The detection of unexpected levels of tritium and/or sodium-22 in groundwater will be evaluated in accordance with the BNL Groundwater Protection Contingency Plan.

The operating procedures, the periodic sampling of onsite drinking water for tritium, the extensive groundwater monitoring program and the long delay times from spill to an onsite or offsite well location preclude the possibility of any worker or member of the public from drinking radioactive groundwater.

Environmental Risks from Biological Materials

There is no credible risk to the environment from airborne releases from the NSRL animal rooms (A1 and A2) in the Support Laboratory, which are Biosafety Level 2. Ventilation is considered a secondary barrier for releases from Biosafety Level 2 facilities. Biosafety Level 2 requirements state, “There are no specific ventilation requirements. However, planning of new facilities should consider mechanical ventilation systems that provide an inward flow of air without re-circulation to spaces outside of the laboratory. If the laboratory has windows that open to the exterior, they are fitted with fly screens."

The NSRL animal laboratories have HEPA filters installed in the room exhaust and in the room re-circulation lines. The requirements for HEPA filtering of exhaust appear in Biosafety Level 3 requirements and even then are only required under certain conditions such as exhausting near occupied areas or ventilation intakes. From this point of view, HEPA testing would not be required since there is no Biosafety Level 2 requirement to have the filters installed. Although testing of HEPA exhaust is not mentioned specifically in the regulations[92], a HEPA filter efficiency test is performed annually.

From a regulatory standpoint, ventilation and exhaust systems for laboratory operations; i.e., lab hoods, are exempt from New York State emission source permitting requirements.

[92] http://www.cdc.gov/od/ohs/biosfty/bmbl4/bmbl4s3.htm

Fire Risks

Based on the extensive use of fire protection, the appropriate location of exits and the use of emergency ventilation exhaust systems, high or medium consequence levels are extremely unlikely. Thus, the fire risk is acceptable.

The maximum credible fire loss in each C-AD facility is documented in the FHA for each facility in the appendices.

Electrical Risks

Based on the use of formal C-A electrical safety procedures, working hot permits and job safety analyses, high or medium consequence levels are extremely unlikely. Thus, the risk is acceptable.

4.5.14. Professional Judgment Issues

The initial screening of C-AD accelerator and experimental facility hazards was performed using qualitative engineering judgment. The C-A engineering, operating and safety staff has many years of experience with BNL accelerators and experiments. This experience influenced the analyses of Appendix 2.

Experience has also influenced the choice of conservative maximum hourly routine and faulted beam energy limits which have been used as the bases for the shielding and ALARA analyses. These judgment issues have always been and will continue to be verified by beam fault studies.

4.5.15. Methods Used in Evaluation of Radiological Hazards

Techniques employed in the evaluation of radiological hazards include the use of empirical formulae,[93,94,95] and the Monte Carlo Programs MCNPX[96] and CASIM.[97] CASIM has been used satisfactorily at BNL accelerators for many years at energies above 10 GeV, and has been extensively compared to MCNPX at energies above 2 GeV.[98] CASIM cannot be used directly for low-energy neutron transport. It has also been found to overestimate neutron flux in the very forward direction.[99] MCNPX is probably the most widely used neutron transport Monte Carlo code. Several MCNPX calculations have shown excellent agreement with empirical labyrinth formula.[100]

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[93] K. Tesch and H. Dinter, "Estimation of Radiation Fields at High Energy Proton Accelerators," Radiation Protection Dosimetry, Vol. 15 No. 2 pp. 89-107 (1986).
[94] C. Distenfeld and R. Colvett, "Skyshine Considerations for Accelerator Shielding Design," Nucl. Sci. Eng. Vol. 26, p. 117 (1966).
[95] A. H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, Kent, England, 1992.
[96] L. S. Waters, Ed., "MCNPX USER'S MANUAL," LANL Report TPO-E83-UG-X-0001, (1999). See also H.G. Hughes, R.E. Prael, R.C. Little, "MCNPX – The LAHET/MCNP Code Merger," X-Division Research Note, 4/22/97. The version number of the code used in this note is 2.1.5.
[97] A. Van Ginneken, "CASIM; Program to Simulate Hadron Cascades in Bulk Matter," Fermilab FN-272 (1975).
[98] A. J. Stevens, "N-Shield, Description," BNL C-A Dept. ES&F Division Note 157 (2000). http://server.c-ad.bnl.gov/esfd/epstechnote.html.
[99] See above reference. The CASIM estimates of soil activation in the dump region are in fact over-estimates. Conversely, CASIM dramatically underestimates neutron flux in the backwards direction, but no such estimates exist in the NSRL geometry.
[100] K. Goebel, G.R. Stevenson, J.T. Routi, and H.G. Vogt, "Evaluating Dose Rates Due to Neutron Leakage Through Access Tunnels of the SPS," CERN LABII-RA/Note/75-10 (1975).

Past measurements by at C-AD accelerators at approximately 90° have been made in BNL soil. They show that dose equivalent and activation calculations are overestimates and should be regarded as upper limits.[101]

The MARS code system is a set of Monte Carlo programs for simulation of three-dimensional hadronic and electromagnetic cascades, and the transport of particles through matter, for particles with energies ranging from a fraction of an electron volt to 100 TeV. This code is expected to be used more often in the future because it includes magnetic and electric field effects on the cascade process. The code is available for the Unix and Linux operating systems, and is distributed by the developers from Fermi National Laboratory.[102]

[101] A.J. Stevens, "Summary of Fault Studies at RHIC." BNL C-A Dept ES&F Note 156 (2000). http://server.c-ad.bnl.gov/esfd/epstechnote.html

[102] The official MARS Web site is http://www-ap.fnal.gov/MARS/, and links there point to many recent applications of the code.

5. Chapter Five, Accelerator Safety Envelope (ASE)

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5.1.Background

The Accelerator Safety Envelope (ASE) formally establishes the set of bounding conditions or constraints on engineered and administrative systems, within which the Collider-Accelerator Department proposes to operate. These constraints are based on the safety analysis documented in Chapter 4 of the Safety Analysis Document (SAD). The ASE assures the validity of the basic set of assumptions used in the SAD safety analysis and ensures that the physical and administrative controls used to mitigate potential hazards are in place.

DOE requires adherence to the approved requirements stated in the Accelerator Safety Envelope because it is the authorization basis for all commissioning and operations activities. This chapter provides an overview of the development of the content of the ASE. The actual ASE is a separate, controlled document that must be approved by DOE. DOE approval is required for all changes to the ASE. As per BNL Subject Area requirements, a proposed draft ASE is submitted to the Laboratory's ESH Committee for review at the time the SAD is submitted for BNL approval.

Section 1 of the ASE is an introduction. The introduction indicates the method used by the Collider-Accelerator Department for change control of the ASE. It indicates how the Department is to treat a variation beyond the constraints described in Sections 2, 3, and 4 of the ASE, and it describes the use of emergency actions that may be taken when actions not consistent with the ASE are needed to protect the public, worker or the environment.

To understand the appropriate level of bounding information or constraints included in Sections 2, 3, 4 and 5 of the ASE, one must first understand the overall flow-down of information from the highest level constraints stated in BNL SBMS requirements to the lowest-level constraints stated in the Department documents such as operating procedures. This flow-down of information generally produces several levels of constraints that provide a defense-in-depth to ensure the safe and environmentally sound operations of the accelerators. The top levels of constraints are placed in the Accelerator Safety Envelope (ASE). The lower levels of constraints are established in the Collider-Accelerator Conduct of Operations document[1] and Operations Procedure Manual.[2]

The highest-level constraints, which are termed "Safety Envelope Limits," are documented in Section 2 of the ASE. These are the absolute limits that BNL places on its operations to ensure that the regulatory limits established to protect the environment, the public and staff and visitors are met.

The next highest level constraints are the operating limits used as a basis for the Safety Analysis Document (SAD) hazard analysis. This level of constraints is termed

[1] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm C-A Conduct of Operations
[2] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/index.htm C-A Operations Procedure Manual

"Corresponding Safety Envelope Parameters," and is documented in Section 3 of the ASE. Section 3 of the ASE identifies the critical operating parameters that ensure the accelerator and experimental operations will not exceed the corresponding Safety Envelope Limits in Section 2 of the ASE.

Although it is an accepted practice for DOE Reactor Facilities, the Accelerator Safety Order neither prescribes nor prohibits a list of alternate actions to Corresponding Safety Envelope Parameters listed in the ASE. However, BNL SBMS requirements indicate that operations procedures addressing ASE-required equipment and systems should specify the minimum necessary system components and monitoring devices to allow operation, and if these minimums are not met, then alternate actions are to be specified in the procedures. C-AD has chosen to also list these alternate actions in the ASE and has termed them "Authorized Alternatives." The equivalence of an Authorized Alternative to a Corresponding Safety Envelope Parameter was thoroughly reviewed. It is acknowledged that the use of an Authorized Alternative might pose a slight increase in risk; however, the C-AD does not consider the increase to be significant. Additionally, the number and depth of Authorized Alternatives listed in the ASE do not indicate that the affected systems are unreliable. It is noted that DOE reactor facilities can have the equivalent of authorized alternatives for all of their safety systems. Further, whenever an Authorized Alternative is used at C-AD, the Department is committed to performing a critique. Authorized Alternatives are listed in Section 3 of the ASE.

Lower levels of safety-related constraints may or may not be included in an ASE. In a large complex facility like C-AD accelerators, lower-level safety-related constraints are contained in much larger controlled documents that are reviewed and updated frequently. As previously indicated, these documents are the Collider-Accelerator Conduct of Operations document[3] and the C-AD Operations Procedure Manual.[4]

The C-AD ASE has been developed primarily to define the important limits for operation within the assumptions of the SAD hazard analyses and to define operability requirements of safety-significant systems. The scope and content of the ASE have been limited to include only the most critical requirements in order to make the ASE operationally useful for controlling the safety of the accelerators and experiments. Because of this philosophy, the details needed to adequately describe the use of lower-level safety-related constraints only appear in operating procedures, which are initially examined by an independent review team during the Accelerator Readiness Review, and subsequently examined and updated every three years by the C-A Department.

These lower-level constraints may consist of documented or measurable limits or administrative controls necessary to establish an operational margin of safety that may be more conservative than that established in the ASE. This operating margin provides a defense-in-depth approach to ensure that the Collider-Accelerator Department will operate the accelerators and experiments well within Safety Envelope Limits and Corresponding Safety Envelope Parameters agreed to by DOE in formally approving the ASE. Lower-level constraints in the C-A OPM generally address requirements for industrial safety, environmental protection, waste management, pollution prevention, radiation protection, ALARA, workplace hazardous materials monitoring, use of personal protective equipment, and occupational health and safety.

[3] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm C-A Conduct of Operations
[4] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/index.htm C-A Operations Procedure Manual

Compliance with lower-level constraints is achieved through training of personnel, self-assessment, periodic management review and each individual's commitment to adhere to requirements in procedures. Examples of lower-level constraints may be related to ASE parameters that are physically designed into the accelerators, such as maximum beam power, maximum beam energy or maximum beam intensity. A physical change to the accelerator would be needed to exceed these ASE parameters. Since C-AD management and staff are expected to adhere to configuration control procedures in the OPM, physical changes to accelerators or experiments would be referred by liaison physicists and liaison engineers to appropriate safety committees and internal and external approval authorities before the change occurred. These configuration control procedures are considered lower-level constraints. Safety committees examine proposed changes to accelerators and experiments and consider the impact on the ASE requirements. Other examples of lower-level constraints are authorizations such as 1) release of an effluent to the sanitary system and 2) radiation safety check-off lists that must be completed prior to start-up of an accelerator for a particular physics program.

5.2. Summary of ASE Content

The basic content of the ASE includes the following sections:

Section 1: Introduction

The following items are included:

- General actions to be taken upon discovery of a violation of the Safety Envelope, including shutdown of the facility.
- A description, or reference, to the method used by the Department for change control of the ASE.

Section 2: Safety Envelope Limits

This section contains two categories of limits: the absolute limits that BNL places on its operations to ensure the Collider-Accelerator Department meets regulatory limits established to protect the environment, public and staff/visitors; and the design/operating limits used as a basis for the SAD.

Section 3: Corresponding Safety Envelope Parameters

This section identifies the measurable limitations on critical operating parameters that, in conjunction with the specifically identified hazard control considerations established by the facility design, construction, or experimental design constraints, ensure the accelerator or experimental operations will not exceed the Safety Envelope Limits. These parameters are derived from the safety analysis in Chapter 4 of the SAD.

Section 4: Engineered Safety Systems Requiring Calibration, Testing, Maintenance, and Inspection

This section includes the identification of the systems and requirements for calibration, testing, maintenance, accuracy or inspection necessary to ensure the continued reliability of engineered safety systems that ensure the operational integrity of parameters listed in Section 3. Requirements are consistent with established BNL Policies.

Section 5: Administrative Controls

This section includes the administrative controls necessary to ensure the operational integrity of parameters listed in Section 3. Included are minimum staffing level requirements, qualification and training requirements for operations, minimum operable equipment, work planning and control systems and environmental release mitigation measures.

6. Chapter Six, Quality Assurance

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6.1. Program

The Collider-Accelerator (C-A) Department has adopted, in its entirety, the BNL Quality Assurance Program. This QA Program describes how the various BNL management system processes and functions provide a management approach which conforms to the basic requirements defined in DOE Order 414.1A, Quality Assurance.

The quality program embodies the concept of the "graded approach," i.e., the selection and application of appropriate technical and administrative controls to work activities, equipment and items commensurate with the associated environment, safety and health risks and programmatic impact. The graded approach does not allow internal or external requirements to be ignored or waived, but does allow the degree of controls, verification, and documentation to be varied in meeting requirements based on environment, safety and health risks and programmatic issues.

The BNL QA Program is implemented within the C-A Department using C-AD QA implementing procedures. These procedures supplement the BNL Standards Based Management System (SBMS) documents for those QA processes that are unique to the C-A Department. C-AD QA procedures are developed by C-AD QA and maintained in Chapter 13 of the C-AD Operations Procedures Manual.

The C-AD QA philosophy of adopting the BNL Quality Program and developing departmental procedures for the implementation of quality processes within C-AD ensures that complying with requirements will be an integral part of the design, procurement, fabrication, construction and operation of the C-AD complex.

A Quality Representative has been assigned to serve as a focal point to assist C-AD management in implementing QA program requirements. The Quality Representative has the authority, unlimited access, both organizational and facility, as personnel safety and training allows, and the organizational freedom to:

- assist line managers in identifying potential and actual problems that could degrade the quality of a process/item or work performance
- recommend corrective actions
- verify implementation of approved solutions

All C-AD personnel have access to the Quality Representative for consultation and guidance in matters related to quality.

6.2. Personnel Training and Qualifications

The BNL Training and Qualification Management System within the Standards Based Management System (SBMS) supports C-AD management's efforts to ensure personnel working within the C-AD complex are trained and qualified to carry out their assigned responsibilities. The BNL Training and Qualification Management System is implemented within the C-A Department with the C-AD Training and Qualification Plan of Agreement.[1]

6.3. Quality Improvement

The BNL Quality Management System, supplemented by C-AD procedures, provides the requirements for identifying, documenting and dispositioning nonconformances and for establishing appropriate corrective and preventive actions that are based on identified causes. The BNL Quality Management System provides guidance for trending nonconformances to recognize recurring, generic or long-term problems.

The decision to initiate quality improvement is based upon an evaluation of the seriousness, and the adverse cost, schedule, safety and environmental impact of the nonconformance relative to the cost and difficulty of its correction. In some cases, corrective action may not be feasible.

The C-AD Self Assessment Program provides information on scientific, business and operational performance for C-A's management, staff, customers, stakeholders and regulators. Self-assessment also provides a mechanism for improving the rules that

[1] http://www.agshome.bnl.gov/AGS/Accel/SND/Training/trainplan.pdf C-A Department Training and Qualifications Plan

govern training and qualifications, documents and records, work process, design, procurement, inspection and testing, and the assessment process itself. The Self-Assessment program evaluates performance relative to critical outcomes and internal performance objectives in order to identify strengths and opportunities for improvements within the C-A Department.

6.4. Documents and Records

The BNL Records Management System and controlled document Subject Areas within SBMS, supplemented by C-AD procedures, provide the requirements and guidance for the development, review, approval, control and maintenance of documents and records.

C-AD documents encompass technical information or instructions that address important work tasks, and describe complex or hazardous operations. They include plans, procedures, instructions, drawings, specifications, standards and reports.

C-AD records are information of any kind and in any form, created, received and maintained as evidence of functions, policies, decisions, procedures, operations, or other activities performed within the Department. Records are retrievable for use in the evaluation of acceptability, and verification of compliance with requirements. C-AD records are protected against damage, deterioration or loss.

6.5. Work Process

Work is performed employing processes deployed through the BNL SBMS. SBMS Subject Areas are used to implement BNL-wide practices for work performed. Subject Areas are developed in a manner that provides sufficient operating instructions for most activities. However, C-AD management has determined that it is appropriate to develop internal procedures to supplement the SBMS Subject Areas. These internal C-AD procedures are bounded by the requirements established by the BNL Subject Areas.

Group leaders and technical supervisors are responsible for ensuring that employees under their supervision have appropriate job knowledge, skills, equipment and resources necessary to accomplish their tasks. Contractors and vendors are held to the same practices.

The Quality Management System, supplemented by C-AD procedures, provides processes for identifying and controlling items and materials to ensure their proper use and maintenance to prevent damage, loss or deterioration.

C-AD management has identified those processes requiring calibrated measuring and testing equipment. Item identification and control requirements are specified, when necessary, in appropriate documents, e.g., drawings, specifications and instructions. Materials undergoing tests or inspections are controlled to avoid the commingling of acceptable items with items of unknown origin or history, thus avoiding inadvertent use.

C-AD management delegates authority to all C-AD personnel to “Stop Work” to avoid unsafe work practices.

6.6. Design

The C-AD staff plans, develops, defines and controls the design of the C-AD complex in a manner that assures the consistent achievement of objectives for productivity, performance, safety and health, environmental protection, reliability, maintainability and availability. Design planning establishes the milestones at which design criteria, standards, specifications, drawings and other design documents are prepared, reviewed, approved and released.

The design criteria define the performance objectives, operating conditions, and requirements for safety and health, reliability, maintainability and availability, as well as the requirements for materials, fabrication, construction, and testing. Appropriate codes, standards and practices for materials, fabrication, construction, testing, and processes are defined in the design documentation. Where feasible, nationally recognized codes, standards and practices are used. When those are either overly restrictive, or fall short of defining the requirements, they are modified, supplemented, or replaced by BNL specifications.

Specifications, drawings and other design documents are used to represent verifiable engineering delineations, in pictorial and/or descriptive language, of parts, components or assemblies in the C-AD complex. These documents are prepared, reviewed, approved and released in accordance with C-AD procedures. Changes to these documents are processed in accordance with the C-AD configuration management procedures.

6.7. Procurement

Personnel responsible for the design or performance of items or services to be purchased ensure that the procurement requirements of a purchase request are clear and complete. Using the graded approach, potential suppliers of critical, complex, or costly items or services are evaluated in accordance with predetermined criteria to ascertain that they have the capability to provide items or services that conform to the technical and quality requirements of the procurement. The evaluation includes a review of the supplier's history with BNL or other DOE facilities, or a pre-award survey of the supplier's facility. C-AD personnel ensure that the goods or services provided by the suppliers are acceptable for intended use.

6.8. Inspection and Acceptance Testing

The BNL Quality Management System within the SBMS, supplemented by C-AD procedures, provides processes for the inspection and acceptance testing of an item, service or process against established criteria and provides a means of determining acceptability. Based on the graded approach, the need and/or degree of inspection and acceptance testing are determined during the activity/item design stage. Inspection/test planning has as an objective the prompt detection of nonconformances that could adversely affect performance, safety, reliability, schedule or cost.

When required, acceptance and performance criteria is developed and documented for key, complex or critical inspection/test activities. If an item is nonconforming, it is identified to avoid its inadvertent use. These processes also specify how inspection and test status are indicated either on the item itself, or on documentation traceable to the item.

The BNL Calibration Subject Area, supplemented by C-AD procedures, describes the calibration process for measuring and test equipment. C-AD management identifies appropriate equipment requiring calibration. The calibration status is readily discernible and associated calibration procedures, documentation, and records are prepared and maintained. Calibrated equipment is properly protected, handled and maintained to preclude damage that could invalidate its accuracy. Measuring and test equipment found out of calibration is identified and its impact evaluated.

6.9. Management Assessment

The managers of the four C-AD Divisions periodically evaluate or “self-assess” the effectiveness of the C-AD organization and present their report to senior management. Through the C-AD Self-Assessment Program, a regular, systematic evaluation process has been established wherein C-AD assesses internal management systems and processes used to make fact-based decisions. For example, see the FY03 C-AD Self-Assessment Plan. The C-AD Self-Assessment Program includes such items as: performance measures; compliance checks; effectiveness evaluations; job assessments; surveys; and environment, safety and health walk-throughs. Strengths and opportunities for improvement are identified. Assessment results are documented and fed back to managers, and provided valuable input into the business-planning process.

C-AD's Environment Management System and Occupational Safety and Health (OSH) Management System and associated activities also undergo management review each year. In addition, these management systems are reviewed by third-party registrars, and federal, New York State and County agencies. Together these elements provide comprehensive and objective information used by C-AD management in establishing strategic direction and improving environmental and OSH performance.

6.10. Independent Assessment

Using the graded approach, C-AD Management periodically evaluates the implementation of the BNL Management Systems, SBMS Subject Areas and C-AD specific processes. This is done through reviews, assessments and/or other formal means. The C-AD QA Group performs these assessments. They include an evaluation of the safety and quality cultures in terms of the adequacy and effectiveness of the management structure, which includes, but not limited to, environment, safety and health, quality, conduct of operations, and training requirements.

Individuals verifying these activities have sufficient authority to access work area, and organizational freedom to accomplish the following: identify problems, initiate, recommend, or provide solutions to problems through designated channels, and verify implementation of solutions.

All assessments are planned and conducted using established criteria. The type and frequency of these assessments are based on the status, complexity and importance of the work or process being assessed. The results are documented, non-conformances and recommendations identified and presented to C-A Department management. The Department develops corrective actions to promote improvement. Actions are tracked to closure by C-AD QA in the Family version of the BNL Assessment Tracking System (ATS). Those conducting independent assessments are technically qualified and knowledgeable in the areas assessed and are independent from the activities assessed. Where necessary, subject matter experts are involved in the assessments to give insight into a particular area.

In addition, peer review is a process used at C-AD by which the quality, productivity and relevance of science and technology programs is monitored and evaluated. In operational and environment, safety and health arenas, peer review is used to evaluate and independently verify engineering design and operational implementation.

7. Chapter Seven, Decommissioning and Decontamination Plan

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7.1. Introduction

The objective of the Collider-Accelerator decommissioning plan, which will be developed near the end of each accelerator's operating lifetime, will be to determine the hazards and risks associated with decommissioning the facilities and to plan the activities required to complete the decommissioning. Ensuring the safety of the workers, protecting the public and the environment and complying with applicable state, local, and federal regulations are of utmost importance in preparing the plan. Management of the operating wastes, or other hazardous materials that might remain in the facility after shutdown, as well as the wastes generated during the decommissioning activities are key to conducting a safe decommissioning. Therefore, an approach that accurately identifies the types and quantities of these materials, thereby establishing the baseline, is an important aspect of the decommissioning planning.

Another aspect of the decommissioning plan will be the determination of the final site configuration or end-point in which each facility or site will be left. Determining the desired endpoint for each site and the risks present are essential to planning. The preferred decommissioning alternative is the Greenfield condition but the following four alternatives will be evaluated at final shutdown:

- re-use for a similar function
- safe storage
- Brownfield condition
- Greenfield condition

It is assumed that federal control will remain in place for a number of years after decommissioning of these accelerators is completed.

Once baseline conditions and an understanding of the volumes of waste to be dealt with are estimated and end-points are chosen, then the methods of accomplishing the decommissioning that will meet the end-point goals can be selected. All C-A facilities currently have similar waste streams. Only the volumes of waste materials and the percent activation vary between the accelerators and experimental areas. Beam intensity and predominant species of particles accelerated are the source of the relative differences in activation levels. All accelerator facilities have recyclable steel, recyclable copper cabling, clean concrete wastes, and miscellaneous clean wastes. Many accelerator facilities have activated steel, activated components, activated copper cabling, activated concrete, miscellaneous activated wastes, activated soil, activated water, mixed-waste electronic components, and mixed-waste lead. There are some facilities that have non-radioactive hazardous materials such as asbestos, beryllium, and lead. Asbestos in particular is present in many buildings at C-AD, primarily in pipe insulation, ceiling tiles, gaskets, thermal insulation, cement boards and pipes, flooring material, and in roofing products. The effectiveness of the decommissioning methods; that is, the method's ability to keep personnel exposures to hazardous and radioactive materials as low as reasonably achievable and to eliminate or significantly reduce the potential impact on the environment are important criteria that are applied in choosing the appropriate method.

Finally, the waste streams to be managed during the decommissioning are to be analyzed in the decommissioning plan, their characteristics and volumes estimated, and treatment and disposal options evaluated. There are multiple waste streams both for non-radioactive waste and radioactive waste to be managed during the decommissioning. Some of the waste streams can be treated and disposed of locally, such as recyclable metals and concrete waste, while some, low-level radioactive waste, mixed waste, liquid low-level radioactive waste, hazardous waste, and industrial waste such as oil, will be shipped off site for disposal.

7.2. Baseline Conditions

Establishing the expected baseline conditions at the end of each facility's operating lifetime can be accomplished by estimating the radioactivity levels and physical conditions based on measurements, calculations, design features, operating procedures, and waste management requirements. The C-A Department Operating Procedures, Environmental Management System, OSH Management System, and BNL SBMS subject areas would provide up to date and current information on the operating history, activation history, environmental impacts, and waste generation and disposal history to help establish the baseline conditions. Design features that help mitigate the impact of potentially high activation levels on the baseline have been incorporated into the C-A facility designs. Examples of such features are beam loss monitors and cutoff devices interlocked to shut off the beam to ensure that OPM beam loss criteria are met thereby reducing inadvertent activation of materials. Impermeable barriers are placed over the soil wherever there are known beam loss areas, such as beam stops, targets and collimators. These impermeable barriers are installed to minimize infiltration of surface water into the activated soil areas.

Beam-line cooling systems are designed as closed-loop systems to minimize the amount of activated water. Operations procedure limits and ASE limits on beam intensity, integrated beam, and beam-loss are examples of administrative controls that help minimize the inadvertent activation of materials. These administrative controls can have a large impact on the cost of the decommissioning since they help ensure that large volumes of soil and water will not have to be handled as low-level-radioactive waste, and activation of beam-line components and magnets will be minimized.

Additionally, methods described in C-A Department Operating Procedures and BNL SBMS Subject Areas are in place to track spills, spill response actions, inventories of all chemicals and to record information on beam-loss events. These records will aid in establishing the baseline. Records of hazardous and radioactive wastes, personnel dose records, area survey records, RWP records, and work planning packages are maintained and provide additional baseline information. Radiological and operations records are maintained according to SBMS requirements. Site, building, and component drawings are maintained by both C-A Department and the BNL Plant Engineering Division to assist in baseline information.

The decommissioning plan will include requirements for characterizing the facilities after operations are shutdown and before actual decommissioning commences.

This characterization will confirm or re-establish the baseline conditions, will be used in performing a risk assessment to support the decommissioning safety assessment, and will help establish surveillance and maintenance required to maintain facilities in a safe standby mode until decommissioning begins.

7.3. End Point Goals

The C-A facilities end-points will be stated early during decommissioning planning because they will form the basis for specific goals and activities that must take place. The goals for the hazard category and safety basis of the deactivated facilities will be established, and determinations will be made of decommissioning safety measures.

Determining the desired product, the final site-configuration and the risks present are essential to planning the decommissioning alternatives for the facilities. The decommissioning plan will address the baseline conditions and consider all the alternatives.

The process of evaluating the best alternative and providing an approach that will result in lowest cost, least amount of exposure of workers to radiation during the decommissioning activities and greatest public acceptance will involve consideration of the pros and cons of each alternative, and rely on the input of all stakeholders including the surrounding community. For example, office, shops, and auxiliary/support facilities will be relatively clean with most items recyclable or clean solid wastes and can be expected to be removed. Accelerator and experimental areas contain many thousands of tons of low-level radioactive shielding and a few tons of highly-activated components. Due to the size and number of buildings and useful components, a combination of re-use, safe storage, and decommissioning of non-useable buildings and components is the likely future scenario to achieve end points in the safest, most cost effective way.

7.4. Regulatory Requirements

The decommissioning plan will delineate the applicable New York State and federal laws, consensus standards, DOE directives and other requirements applicable to the decommissioning activities, especially those required to meet the end point criteria.

Regulations affecting decommissioning fall into three categories:

- those that directly affect decommissioning, e.g., the removal of radioactive materials as needed to reduce risk
- those that protect the worker and the public during decommissioning operations
- those that apply if hazardous or toxic materials are present in the facility

A number of DOE orders and federal regulations actually cover two or more of these categories, so there may be overlapping requirements across categories. Sound planning for interacting with the regulatory agencies and compliance with these regulatory requirements are critical to timely and successful completion of decommissioning activities and will be an integral part of the initial planning activities.

7.5. Decommissioning Methods

Decommissioning methods will be chosen based on radiological conditions at the accelerator and experimental facilities at the time of the final shutdown and the effectiveness of the methods to achieve the desired end-points. Many C-AD facilities such as shops, offices, auxiliary and support buildings are clean and will require only standard decommissioning techniques. Based on archival radiological data, all seven accelerators and all external beam lines can be largely contact handled to remove both the components and the activated shielding at final shutdown. A few highly radioactive parts such as beam stops, target caves, and beam interaction areas may require remote non-contact handling, at least for a period of 1 to 5 years post shutdown. Additionally, while there are only a few contamination areas and contaminated parts at C-A Department, these areas and components will require surface decontamination techniques applied before significant disassembly work is attempted. Therefore, a variety of techniques and removal methods will be analyzed to select approaches that accomplish the goals and optimize safety to the workers and protection of the environment as well as efficiency.

The decommissioning plan will describe methods that accommodate these varying conditions while maintaining ALARA principles as the basis for the cost estimate. Design features that will reduce personnel exposure as well as decommissioning costs will be addressed. The plan will address the conditions and hazards in detail and will have the benefit of additional information and technologies not yet available. The activation levels will be known in detail, which will allow determination of protection requirements to prevent unwarranted exposure of the workers to radiation.

7.6. Waste Streams

There will be multiple waste streams to be managed during decommissioning. Some of the clean material will be recycled, treated and/or disposed of locally, while much of the radioactive and hazardous waste will be sent off-site for disposal. All recyclable materials and wastes anticipated from the decommissioning operation will be identified in the decommissioning plan. Based on the general nature of the decommissioning operations and the applicable requirements, an all-inclusive list of waste categories will be identified as part of the decommissioning plan. The list will include recyclable materials, radioactive components, hazardous chemicals, and industrial wastes and any equipment or materials being saved for reuse even though they might not be classified as wastes under the Resource Conservation and Recovery Act.

The C-A Department has been in operation for many years and has been disposing of approximately 3000 ft^3 of low-level radioactive waste, 30 ft^3 of mixed waste, 1200 gallons of activated water, and 30,000 lbs. of hazardous and industrial waste each year. Based on the advice and assistance of experts in BNL's Environmental and Waste Management Services Division, we have a thorough understanding of the treatment requirements of all our waste streams, the off-site disposal sites' acceptance criteria, and the shipping and packaging criteria. The decommissioning operations will necessitate larger volumes of wastes but will consist of all of the same types of wastes that we currently deal with routinely.

The decommissioning plan will review all waste treatment facilities and required processes at the time of the decommissioning. Several low-level radioactive waste disposal facilities, such as Hanford, are currently used by BNL Environmental and Waste Management Services Division today, and it is assumed that these facilities, or equivalent facilities, will be available in the future. Cost estimates and waste volume estimates will be made at the time of the decommissioning plan development.

8. Chapter Eight, References/Acronyms/Units/Links

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8.2. Acronyms

AC – Alternating Current

ACS – Access Control System

AGS – Alternating Gradient Synchrotron

AHJ – Authority Having Jurisdiction

AISC - American Institute of Steel Construction

ALARA – As Low As Reasonably Achievable

ANSI – American National Standards Institute

ASE – Accelerator Safety Envelope

ASME - American Society of Mechanical Engineers

ASSRC – Accelerator Systems Safety Review Committee

ASTM - American Society for Testing and Materials

ATR – AGS to RHIC Transfer Line

ATS – Assessment Tracking System

AVS – American Vacuum Society

AWS – American Welding Society

BAF – Booster Applications Facility

BIS – Beam Instrumentation System

BHSO – Brookhaven Site Office

BLIP – Brookhaven Linac Isotope Producer

BNC – Baby N Connector (slang)

BNL – Brookhaven National Laboratory

BPM – Beam Position Monitor

BtA – Booster to AGS

BRAHAMS - Broad Range Hadron Magnetic Spectrometer

BSA – Brookhaven Science Associates

BTMS – Brookhaven Training Management System

C-A – Collider-Accelerator

CA – Controlled Access

CAP88-PC - Clean Air Act Computer Code

CAS – Collider-Accelerator Systems Watch

CASIM – Cascade Simulation Computer Code

CEE – Chief Electrical Engineer

CFR – Code of Federal Regulations

CGA – Compressed Gas Association

CME – Chief Mechanical Engineer

CP – Charge – Parity

DC – Direct Current

DCG – Derived Concentration Guides

DNA – Deoxyribonucleic Acid

DOE – Department of Energy

DOT – Department of Transportation

DWS – Drinking Water Standard

EAGAL – Experimental Area Group Alarm

EBIS – Electron Beam Ion Source

ECR – Environmental Compliance Representative

EJMA - Expansion Joint Manufacturers’ Association

EMS – Environmental Management System

EPA – Environmental Protection Agency

ES&F – Experimental Support and Facilities Division

ESH – Environment, Safety and Health

ESHQ – Environment, Safety, Health and Quality

ESRC – Experimental Safety Review Committee

FEB – Fast External Beam

FHA – Fire Hazards Analysis

FUA – Facility Use Agreement

HEBT – High Energy Beam Transport

HENP – High Energy and Nuclear Physics

HEPA – High Efficiency Particulate Air (filter)

HITL – Heavy Ion Transfer Line

HTB – HITL to Booster Line

HV – High Voltage

HVAC – Heating, Venting and Air Conditioning

HZE – High Energy High Z Particles

IACUC – Institutional Animal Care and Use Committee

IBC – Institutional Biosafety Committee

IR – Interaction Region in RHIC

IRB – Institutional Review Board

ISM – Integrated Safety Management

ISO – International Standards Organization

KOPIO - K Zero to Pi Zero

LE – Liaison Engineer

LEC – Local Emergency Coordinator

LET – Linear Energy Transfer

LP – Liaison Physicist

LOTO – Lock Out / Tag Out

LRM – Long Radiation Monitor

MCNPX – Monte Carlo Neutron Photon Transport Computer Codes

MCL – Maximum Contaminant Level

MCR – Main Control Room

MEBT – Medium Energy Beam Transport

MECO - Muon to Electron Conversion

MHV – Miniature High Voltage

MMPS – Main Magnet Power Supply

MPFL - Maximum Possible Fire Loss

MS – Management System

MSS – Manufacturers Standardization Society

NASA – National Aeronautics and Space Administration

NCRP – National Council on Radiation Protection and Measurements

NEG – Non-Evaporative Getters

NEPA – National Environmental Policy Act

NESHAP - National Air Emission Standards for Hazardous Air Pollutants

NFPA – National Fire Protection Association

NIH – National Institutes of Health

NMC – Nuclear Measurements Corporation

NSRL – NASA Space Radiation Laboratory

NYS – New York State

OPM – Operations Procedure Manual

ORPS – Occurrence Reporting and Processing System

OSHA – Occupational Safety and Health Administration

OSH – Occupational Safety and Health

P2 – Pollution Prevention

PASS – Personnel Access Safety System

PCB – Poly Chlorinated Biphenyl

PE – Plant Engineering

PHENEX - Pioneering High Energy Nuclear Interaction eXperiment

PHOBOS - not an acronym

PLC – Programmable Logic Controller

PMT – Photo-Multiplier Tube

PPE – Personal Protective Equipment

PVC – Poly Vinyl Chloride

QA – Quality Assurance

QA1 – Quality Assurance Category 1

QGP – Quark Gluon Plasma

R2A2 – Roles, Responsibilities, Accountabilities and Authorities

RadCon – Radiological Control

RBE – Relative Biological Effectiveness

RCRBSJ - Research Council on Riveted and Bolted Structural Joints

RCT – Radiological Control Technician

RF – Radio Frequency

RFQ – Radio Frequency Quadrupole

RHIC – Relativistic Heavy Ion Collider

RSC – Radiation Safety Committee

RSVP - Rare Symmetry Violating Processes

RWP – Radiation Work Permit

S&T – Science and Technology

SACR – Scientific Advisory Committee for Radiobiology

SAD – Safety Assessment Document

SAR – Safety Analysis Report

SBC – Standard Building Code

SBMS – Standards Based Management System

SCBA – Self-Contained Breathing Apparatus

SCDHS – Suffolk County Department of Health Services

SEB – Slow External Beam

SEC – Secondary Emission Chamber

SEU – Single Event Upset

SFPC – Standard Fire Prevention Code

SLC – Allen Bradley Trade Mark for a given series of logic controller

SMCS - Safety Monitor and Control System

SPDES – State Pollution Discharge Elimination System

SSPC – Society for Protective Coatings

STAR - Solenoidal Tracker at RHIC

STP – Sewage Treatment Plant

SUNY – State University of New York

SWIC – Segmented Wire Ionization Chamber

TLD – Thermo-Luminescent Dosimeter

TTB – Tandem to Booster Transfer Line (HITL plus HTB)

TRIUMF - Canada's National Laboratory for Particle and Nuclear Physics

TVDG – Tandem Van De Graaff

UL- Underwriters Laboratories

UPS – Uninterruptible Power Supply

USDA – United States Department of Agriculture

VME - Versa Module Europa

WOSH – Worker Occupational Safety and Health

8.3. Units

GeV – billion electron volts, a unit of energy (1 GeV = $1x10^9$ electron volts)

Hz – hertz, a unit of frequency (1 Hz = 1 cycle/second)

MGD – a unit of volumetric flow rate, million gallons per day

mb – milli-barn, a unit of cross-sectional area (1 mb = 10^{-27} cm^2)

mil – a unit of length (1 mil = 0.001 inch)

mT – a unit of magnetic field strength (1 mT = 10 gauss)

mrad – a unit of absorbed dose (1mrad = $6.242x10^4$ GeV/g)

mrem – a unit of dose equivalent (1 mrem = 1 mrad x modifying factors)

ppm – a ratio of mass of component to mass of solution, parts per million

radian – a unit of angle (1 radian = $180^o/\pi$)

TP – a unit of protons (1 TP = $1x10^{12}$ protons)

Torr – a unit of pressure (1 Torr = 1 mm Hg)

μCi – a unit of radioactivity (1 μCi = $3.7x10^4$ disintegrations per second)

10CFR835 ALARA Design Document for C-AD

Background

From 10CFR835 § 835.1002, Facility Design and Modifications:

During the design of new facilities or modification of existing facilities, the following objectives shall be adopted:
(a) Optimization methods shall be used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls.
(b) The design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupational occupancy (2000 hours per year) shall be to maintain exposure levels below an average of 0.5 mrem (5 microsieverts) per hour and as far below this average as is reasonably achievable. The design objectives for exposure rates for potential exposure to a radiological worker where occupancy differs from the above shall be ALARA and shall not exceed 20 percent of the applicable standards in § 835.202.
(c) Regarding the control of airborne radioactive material, the design objective shall be, under normal conditions, to avoid releases to the workplace atmosphere and in any situation, to control the inhalation of such material by workers to levels that are ALARA; confinement and ventilation shall normally be used.
(d) The design or modification of a facility and the selection of materials shall include features that facilitate operations, maintenance, decontamination and decommissioning.

With regard to 10CFR835 § 835.1002 (a), optimization methods are prescribed in C-A OPM 9.5.6, ALARA Optimization and Cost Benefit. The purpose of that procedure is to compare dose savings over the life of a system to the cost of the design, installation and maintenance. Cost-benefit analysis is a technique that helps optimize a given radiation protection practice or it is used to select between proposed practices. The C-AD liaison engineer and liaison physicist, with the help of C-A Department ALARA Committee members, perform the analysis. The ALARA Committee Chair may elect to perform a qualitative analysis or a quantitative analysis.

The following considerations are addressed for a qualitative approach to the analysis:
- Identification of the system or component
- Recognition of the affected groups and their needs
- Selection of the alternatives to be evaluated
- Decision to select from the available alternatives

As an option, an analysis may be used for a quantitative cost-benefit determination. If selected as the optimization method, then a calculation of collective dose for the operation over the time under consideration must be made. The dose may be based on archival reports, operation and maintenance histories, survey results, occupancy and other relevant data. The computation of collective dose is as follows:

(Person-rem/job) (Jobs/year) (Years) = Collective Dose

One must calculate the collective dose for the same period considering the alternative that employs a dose-reduction option. The alternative also may be justified if it can enhance system safety or reliability. If a reasonable alternative does not exist, a quantitative cost-benefit analysis is not warranted.

For quantitative analysis, one evaluates the cost of each alternative in terms of:

- Manpower requirements
- Design and engineering cost
- Operating and maintenance cost
- Retirement and disposal cost
- Radiation exposure to implement the alternative, to maintain and operate the system or component and to dispose of equipment and facilities

For purposes of quantitative cost-benefit analysis, a value of $11,000 per person-rem is used by the C-A Department. For each alternative, one obtains the product of collective dose and $11,000/person-rem. The monetary value of $11,0000 per person-rem is based on a monetary value used by nuclear power plants in the United States to assist in management decisions regarding dose reduction plant modifications or equipment investments.[1] One compares this monetary value with the cost of the alternative. After all costs are determined, political, social and programmatic factors are considered. Based on cost-benefit analysis and the other factors, one selects the appropriate alternative.

With regard to 10CFR835 § 835.1002 (b), the design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupancy, 2000 hours per year, is to maintain exposure levels below an average of 0.5 mrem per hour and as far below this average as is reasonably achievable. The design objective for exposure rates where occupancy is not continuous is ALARA and does not exceed 1 rem per year. See C-A OPM 9.1.12 Procedure for Review of C-A Shielding Design.

With regard to 10CFR835 § 835.1002 (c), the design objective for C-AD for the control of airborne radioactive material is to avoid releases to the workplace atmosphere and to control the inhalation of such material by workers to levels that are ALARA; and to use confinement and ventilation. See C-A OPM, 9.5.2 ALARA Design Review.

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[1] North American ALARA Center, College of Engineering, University of Illinois, http://hps.ne.uiuc.edu/isoedata/html/Dollars_per_Person_REM_Saved.htm

With regard to 10CFR835 § 835.1002 (d), the design of C-AD and the selection of materials include features that facilitate operations, maintenance, decontamination and decommissioning. See C-A 9.5.4.e, Summary of C-A ALARA Practices.

From Section IV, Subsection H, DOE G 441.1-2, "Occupational ALARA Program Guide for use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection:"

The level of effort involved in documenting ALARA decisions should be commensurate with the potential dose savings to be realized. A detailed evaluation need not be made if its cost, including the cost of documentation, outweighs the potential value of the benefits. The procedure used to evaluate the "appropriateness" of dose-reduction and contamination minimization decisions should be maintained. The RCS and PNL-6577 provide additional guidance on optimization methodologies.

From Section IV, Subsection I:

The ALARA design review should have six discrete phases:

1. Dose assessment.
2. Review of radiological conditions against the trigger levels established by management, e.g., creation of a new radiation source or an increase in the dose rates from an existing source; increased operations, maintenance, production, research, inspection or decommissioning requirements in a radiological control area; projected expenditure of a collective dose of greater than 1,000 mrem.
3. Identification of the applicable radiological design criteria.
4. Review of previous similar jobs, designs and processes that have similar hazards to assist in the selection of design alternatives and selection of optimum alternatives using approved optimization methods for evaluating the various ALARA considerations.
5. Incorporation and documentation in the design package of features to reduce dose and the spread of radioactive materials.
6. Post-construction reviews of effectiveness of engineering features to reduce dose and the spread of radioactive materials to provide feedback to the design engineers and help refine the design process.

The procedure describing the process of ALARA design review, including the results of dose assessments, the review of ALARA criteria, the optimization/cost-benefit analysis records, and the recommendations on features to reduce dose and radioactive contamination has been approved by management of the Collider-Accelerator Department and BNL. See C-A OPM, Chapter 9 and SBMS Subject Area, Accelerator Safety.

The ALARA design review record is part of this document and is included such that the records are readily retrievable. Radiological design considerations are discussed in C-A OPM 9.5.2, ALARA Design Review and SBMS, Design Practice for Known Beam Loss Locations.

Six Discrete Phases of ALARA Design Review for C-AD

Dose Assessments

Maximum annual dose to a C-AD User (experimenter) occupying the Support Laboratory 1500 hours per year is 10 mrem. The maximum dose point is the mouth of the labyrinth leading to the Target Hall.[2] Occupancy is expected to average about 4 to 5 people for 1500 hours per year. The maximum estimated collective-dose to Users in the Support Labs is about 50 person-mrem per year.

The estimated doses[2] from skyshine at the closest occupied non-C-AD facilities are:

- 0.27 mrem per year at Building 919, which is a C-AD beam-line component assembly-area, and occupancy is 2000 hours per year by 3 to 4 people.
- 0.0013 mrem per year at Building 931A (BLIP), and occupancy is part time by 1 to 3 people.

The collective-dose from C-AD operation is negligible.

Dose from airborne radioactive emissions at site boundary is 0.00001 mrem per year.[3] The collective-dose is negligible.

Dose to Users in the Target Hall from beam-stop gamma-shine is taken as the product of four factors:

1) The steady-state dose rate at 1 meter from short-lived activation, 16 mrem/h.[4]
2) 22.5% single-person occupancy, which is the percentage operation time assumed to be needed to place targets at the target station.
3) 1500 hours of operation per year.
4) A factor to correct for distance.

The percentage occupancy was based on one person for 30 seconds every 5 minutes to change samples and two persons for 15 minutes every 4 hours to set up a new set of experiments. The distance from the re-entrant cavity to the target station is about 3 m. Assuming a volumetric cylindrical source of activation products and assuming Users stand 2 m from the face of the re-entrant cavity leading to the beam stop, then the unshielded collective-dose estimate is about 650 person-mrem per year, or a cost of $7,200 per year. A 2-inch thick iron shield at the face of the re-entrant cavity would reduce this collective dose estimate by about a factor of four to 170 person-mrem per year.

Review of Radiological Conditions versus Trigger Levels

There are no ALARA trigger levels for instantaneous or short-term incremental quantities for dose-equivalent rate in units of mrem/h or mrem-in-one-hour, respectively since exposure at C-A facilities is not due to continuous level sources of radiation. Instead, C-

[2] BAF SAD Appendix 1. Dose point is entrance to labyrinth leading to Target Hall.
[3] BAF SAD Appendix 4.
[4] BAF SAD Appendix 7.

A Department ALARA design triggers are in terms of collective dose to persons, which is impacted by factors such as distance from the source and occupancy time.

In addition, there are radiological triggers that are related to ALARA design review but are not in themselves related to the level of radiation protection. For example, triggers used solely to gain public acceptance dominate the ALARA design review for activated soil, but the costs for capping activated soil to prevent rainwater infiltration are not part of a cost-benefit analyses for radiological protection. That is, a water repellant cap along the entire length of the C-AD tunnel is required based on a trigger of potentially exceeding 5% of the Drinking Water Standard in groundwater regardless of the cost of capping. The cap will likely prevent any contamination of the aquifer. However, no radiological dose to people is expected if a cap is not installed and contamination occurs. This is because drinking water supply wells are too distant from the source.

The Collider-Accelerator Department has the following four collective-dose levels that trigger a formal ALARA design review by the C-A ALARA Committee:[5]

- Installation of a new accelerator system, experiment, or beam-line component expected to result in > 750 person-mrem collective exposure.
- Operation of a beam-line component, experiment or accelerator system during its lifetime expected to result in > 750 person-mrem/year averaged over a two-year period.
- Future routine maintenance of a new beam-line component, experiment or accelerator system expected to result in > 0.75 person-rem/year averaged over a two-year period.
- Replacement, removal or rebuilding an existing beam-line component or accelerator system expected to result in > 0.75 person-rem/upgrade.

Collective-dose to Users in the Support Laboratories and the Target Hall, collective-dose to occupants at nearby facilities, and collective-dose to persons at the site boundary do not meet any of these triggers. While not meeting a trigger, the potential dose to Users in the Target Hall from beam-stop gamma-shine was judged to require further study, hence Appendix 7 was developed and the following statements further document a specific cost-benefit analysis for shielding out the gamma-shine from the beam stop.

In the ALARA design review process at C-A Department, the need for further study is generally obvious and the focus is normally on possible design options that have different implications for protection, cost and other factors. The performances of the options are usually predicted together with the operational implications. We note, for example, the number of legs to the labyrinth was optimal; that is, more legs or fewer legs produced higher dose estimates. With regard to the Target Room roof shield, the thickness of concrete was based on soil activation considerations. However, the combined concrete and soil layers of the Target Room roof were based on several factors including steepness of the berm and sky-shine dose estimates. With regard to beam path in air in the Target Room, programmatic needs were considered in optimizing the length of the vacuum pipe.

[5] C-AD OPM 9.5.2, ALARA Design Review.

In the case of exposure of Users to residual radiation from the C-AD beam stop, cost, protection and other factors were considered and details are given here.

A specific ALARA investment is a 2-inch plate of iron or equivalent material that moves into place when a person enters the Target Room in order to shield out the gamma radiation from the activated beam stop. It is estimated to take 30 seconds to move such a shield into place. Based on one entry every 5 minutes to change a sample, approximately 20% more time (one minute every 5 minutes) is needed to move the shield into and out of the beam path before each experimental irradiation. Some of this time will overlap with the time it takes to enter and exit the target room if the shield's motion begins as a person enters or leaves. Integrated over a 1500-hour running period, the shield may idle the program significantly each year because of the delay involved in moving the shield. The cost of additional electric power to keep the beam line idle and ready for beam is significant. Approximately 0.5 MW are needed to maintain that portion of the beam line that would remain on during accesses to change samples in the Target Room. At this time (FY2001), the cost per MW-hr is $60. For a 7% increase in idle time, one hundred hours per year, the cost is $3000. A 7% increase is used as opposed to the full 20% increase since some time overlaps with User access and egress. In addition to this cost, the cost of the movable shield itself is approximately $7,000. This includes the cost of labor for fabrication and installation ($2000), materials ($3000), and security hook-up ($2000). It is noted that interlocks are needed to ensure the shield is out of the beam path during irradiations.

Additional factors such as impact on experiments and reduced area allotted for experiments are also considered. For example, frequent rapid entry may be needed for certain types of experiments or experimental runs. In this case, the shield would not be used. Quick entry, simple target mounting and quick exiting procedures would be the focus of ALARA efforts. On the other hand, for some experiments significant set-up time may be called for and a beam-stop shield would be beneficial. Finally, the area allotted for experiments is limited due the fixed size of the Target Room. The shield and mechanism to move the shield may need to be removed in order to accommodate a future experiment.

Based on the above, a cost-benefit analysis does not suggest a movable shield for the Booster beam stop is warranted. Total cost is about $10,000 and total benefit is about $5400 since dose from the gamma-shine is reduced, not eliminated. However, other factors, which are desire to minimize User exposures and cultivation of good will, dominate the eventual decision, even though these factors are not part of the cost-benefit analysis. Thus, a movable shield will be installed and it will be used whenever practicable.

The use of a person-rem period of one year is reasonable in this case. One can choose between short-term cost-benefit analysis and long-term cost-benefit analysis. In this case, power costs were annualized and future dose received by Users was not discounted to account for dose received during shield repairs or removal. The future costs of decommissioning were not included nor were the costs of future annual interlock testing and repair. These types of costs are pertinent to long-term cost-benefit analysis. On the detriment side of the equation, there was an assumption in the dose calculation of 30 days of continuous irradiation with full beam on the dump. It was also assumed that Users worked only on the downstream side of the target, which pushed the short-term dose estimate upward. One could include future years' dose to Users and do a long-term cost benefit analysis, but one should consider the actual up and down running period that is likely to occur, and the actual positions of users. One would need to account for buildup and decay at night, on weekends and during downtimes. In addition, one needs compare this future detriment against all the long-term costs of the shield. The short-term approach was done in the spirit of DOE G 441.1-2, whereby the level of effort involved in documenting ALARA decisions should be commensurate with the potential dose savings to be realized.

Identification Of The Applicable Radiological Design Criteria

From the SBMS Subject Area for Accelerator Safety, the applicable BNL design criteria, which have been met, are:

- Less than 25 mrem in one year to individuals in other BNL Departments or Divisions adjacent to the C-AD.
- Less than 5 mrem in one year to a person located at the site boundary.
- Offsite drinking water concentration and on-site potable well water concentration less than 4 mrem to an individual in one year from C-AD operations.
- Less than 1000 mrem in one year to a Collider-Accelerator Department staff member or User from operation and maintenance of C-AD.
- Less than 10,000 pCi/L tritium concentration of in the BNL sanitary sewer effluent caused by liquid discharges from C-AD averaged over a 30-day interval.
- Groundwater contamination from C-AD soil activation is to be prevented.
- Less than 0.1 mrem in one year to a person at the site boundary from C-AD airborne effluents.

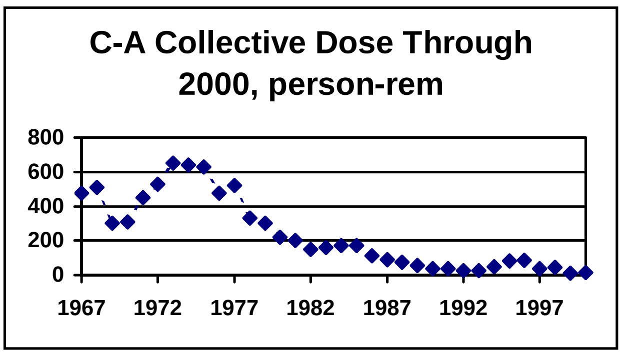
It is noted that the C-A Department planned the C-AD shielding with ALARA in mind, which is that during normal operations, the dose rate on accessible outside surfaces of the shield is planned to be less than 0.25 mrem/h in areas under access control.[6] Assuming 100% occupancy at the shield face, a 2000-hour per year residence time yields an acceptable ALARA design objective of 500 mrem. The 500 mrem per year ALARA design objective is one half the design objective stated in 10CFR835 § 835.1002 (b). Since there are many ways to control access and residence time by area designation, training, signage and work planning and since there is a decrease of dose rate with distance from the shield face, significantly higher shield face doses are often acceptable, but well within the ALARA design objective.

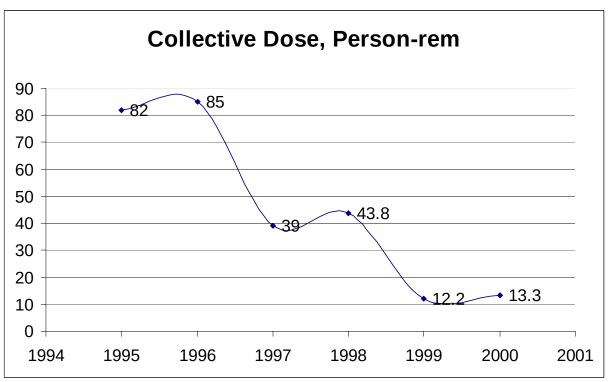
[6] See the BAF SAD Chapter 4, Section 4.6.1.1.

Review Of Previous Similar Jobs, Designs And Processes That Have Similar Hazards

Based on actual monthly doses for the 1999 and 2000 operating cycles for RHIC and NASA programs, approximately 250 person-mrem are accumulated per month of collider-accelerator operation and 1500 person-mrem per month of collider-accelerator maintenance.[7] Collider-accelerator operations were performed with high-energy heavy-ions similar to the proposed NASA program at C-AD; however, dose from maintenance reflects high intensity proton operations as well. These values of collective dose are for Collider-Accelerator staff and Users who are radiation workers. Given that heavy ions from C-AD program represent less than 0.01% of the total nucleons accelerated in the Booster in any given year, it is unlikely that C-AD will affect C-A Department collective dose to any significant extent.

Collective-dose from operations and maintenance of the TVDG, Linac, Booster and AGS accelerators were factored into the monthly collective-dose estimates. It is noted that only the TVDG or Linac and the Booster are required for C-AD heavy ion or proton operations. Overall, radiation exposure reduction is managed effectively at the complex; see the following figures. It is noted that physics programs, the number of radiation workers and the beam intensity have been increasing over the last four decades while the collective dose has been steadily decreasing.





The greatest amount of dose-reduction has come by way of Accelerator Improvement Projects. Funds from these projects were used by the C-A Department to improve the

[7] BNL Memorandum, C. Schaefer to D. Lowenstein, C-A FY 2001 Collective Dose Goal, October 12, 2000.

reliability of vacuum systems, beam injection systems and beam extraction systems. Additionally, the Experimental Support and Facilities Division designed radiation-hardened magnets that can operate properly after very high doses. This has resulted in fewer repairs, which in turn reduces the dose burden because staff is working less frequently on broken, activated equipment. Additionally, the Accelerator Division has improved beam monitoring systems and procedures that achieve better control of beams, which results in less activation of equipment.

C-AD Features To Reduce Dose And The Spread Of Radioactive Materials

- Soil is capped with a water-impermeable membrane to prevent soil activation from becoming a leachate that can reach groundwater.
- Multi-leg penetrations and labyrinths are used to minimize routine radiation levels.
- A re-entrant cavity and movable shield are used to minimize exposure to residual radiation in the Target Room from beam stop radioactivity.
- A sample translator or relay apparatus is used, when applicable, to minimize entrances to the Target Room.
- A sump and sump alarm are located in the beam line to capture cooling water should it leak.
- All drain piping in the facility is connected to the BNL Sanitary Sewage System.
- All cooling water systems have water make-up alarms.
- There are no outdoor tritiated water piping or cooling systems.
- An isolated closed cooling-water system was used to reduce the volume of tritiated water.
- The domestic water supply is equipped with back-flow preventers to isolate the Booster Applications Facility domestic water supply systems.
- Hoods and individual laboratory ventilation are used for radioactive tracer materials and hazardous materials in the Support Laboratories.
- Air and short-lived airborne radioactivity are re-circulated to allow for decay in the Booster Applications Facility beam line during operations.
- Air emissions from the Target Room are vented to the outside. Airflow direction is from the Support Laboratories into the Target Room and out the exhaust point.
- Dual, fail-safe interlocks are used on gate entrances.
- Interlocked access-key-trees are used to capture gate access keys.
- An iris reader or a similar bio-identification system is used to release an access key to a trained individual.
- Crash cords are mounted inside the target cave and beam line.
- Interlocking area radiation monitors with pre-set trip levels are located throughout the Booster Applications Facility.
- Audible and visual warnings are issued before re-enabling the beam line and target cave to receive beam.
- The beam line and Target Room are fully enclosed to prevent access during operations.
- Fencing is used to limit access to other radiological areas.
- Shielding is thick enough to prevent exposure to primary beam.

Post-Construction Review Of Effectiveness Of Engineering Features

The following post-construction reviews are required by C-A OPM procedures:

- Activated soil caps are examined for cracks, tree or shrub root penetration and standing water annually, before each running period.
- Fault studies aimed at proving the effectiveness of shielding and the optimum placement of fixed radiation monitors are conducted before routine operations.
- The access control system is tested before operations with beam and annually thereafter.
- Fencing and posting is examined by the liaison engineer and liaison physicist before initial operations with beam, and before each running period thereafter.
- Groundwater monitoring results are examined annually by C-AD management.
- Collective-dose is reviewed by the ALARA Committee annually.

C-AD Risk Assessment Screening

Table A2-1 Risk Assessment for Vacuum Hazards

FACILITY NAME: C-AD
SYSTEM: Vacuum Beam Line
SUB-SYSTEM: Vacuum System, Beam Window
HAZARD: Vacuum

Event	Structural failure of vacuum boundary
Possible Consequences, Hazards	Implosion of any vacuum component could pose a potential health risk from flying objects.
Potential Initiators	Failure caused by worker mistake or inadvertent striking contact with vacuum boundary.

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Hazard Mitigation	1. Beam line vacuum components designed to meet C-A/industry standards 2. Vacuum and pressure systems reviewed by the C-A Chief Mechanical Engineer or his designate 3. Vacuum components, except for windows, are constructed of heavy-walled material, per ASME Boiler and Pressure Vessel Code, Section VIII to minimize the threat of implosion when evacuated 4. Training of Users and Staff

Risk Assessment Following Mitigation

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	(X) Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-2 Risk Assessment for External Events

FACILITY NAME: C-AD
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: External Event (Earthquake, Tornado, Hurricane, Flood, Aircraft Impact, Forest Fire)

Event	External event impacts C-AD
Possible Consequences, Hazards	Personnel injuries, equipment/building damage or programmatic impact
Potential Initiators	Earthquake, severe weather, flooding, forest fire, aircraft impact

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	() Unlikely	(X) Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Hazard Mitigation	1. Building designed to Uniform Building Code 2. Relatively small radioactive inventory cannot cause offsite health effects 3. BNL Fire Department can respond quickly to forest fire. BNL has firebreaks 4. No active systems needed to protect personnel from adverse health effects after accelerator off 5. Severe weather and flooding potential is extremely low; warning of these impending hazards will allow for accelerator shutdown and for personnel safety 6. BNL Wildfire Prevention Program

Risk Assessment Following Mitigation

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	() Unlikely	(X) Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-3 Risk Assessment for Electric Shock

FACILITY NAME: C-AD
SYSTEM: Facility
SUB-SYSTEM: Magnets, Power Supplies, Instrumentation
HAZARD: Electric Shock from Exposed Conductors

Event	Worker contacts energized conductor
Possible Consequences, Hazards	Shock, impact injury, burns
Potential Initiators	Worker falls, fails to control position of limbs or tools, equipment failure, improper work controls

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	(X) High Risk	() Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. Exposed conductors and terminals are covered for protection of personnel as per BNL and C-AD Electrical Safety requirements 2. Training for workers / experimenters 3. Use of work planning, LOTO and Working Hot Permits 4. Magnets de-energized when routine access allowed into tunnels/rings or are completely protected from personal contact 5. Review is performed for electrical safety on all non-commercial 'in-house' built equipment. Review is by the Chief Electrical Engineer or his designate

Risk Assessment Following Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	(X) Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N <u>Yes</u> If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N <u>Yes</u> If Yes, need ASE requirement.

Table A2-4 Risk Assessment Radiation Exposure Outside Enclosures

Facility Name: C-AD
System: Areas Outside Beam Enclosures
Sub-System: Accelerator Berm Shields, Beam-line Shields, Entrances to Accelerators , Target Areas and Experimental Areas, Penetrations to Beam Enclosures
Hazard: Prompt Beam Radiation Outside Beam Enclosures

Event	Credible beam control fault
Possible Consequences, Hazards	Unwarranted radiation exposure due to abnormal radiation levels outside concrete and earth berm shielding, fenced areas, penetrations and chicanes
Potential Initiators	Failure of magnet or magnet power supply, inefficient beam tuning

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Hazard Mitigation	1. Beam information display and operating procedures. Beam tuned at low intensity 2. Operator / Physicist / User training 3. Review of radiation safety design of shields and penetrations by C-A RSC 4. Radiological area postings, fenced gates interlocked with beam, locked gates 5. Area radiation monitors alarm locally and in MCR during periods of abnormal radiation levels 6. Area radiation monitors interlock beam off during periods of abnormal radiation levels 7. Sweep procedures prior to beam initiation 8. Beam intensity limits 9. Periodic inspection of earthen berm to verify integrity

Risk Assessment Following Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	(X) Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-5 Risk Assessment for Radiation Exposure Inside Enclosures

FACILITY NAME: C-AD
SYSTEM: Beam Enclosures
SUB-SYSTEM: C-AD Beam Line Tunnel, Target Room
HAZARD: Prompt Beam Radiation inside Beam Enclosures

Event	Person inside enclosure during beam operation
Possible Consequences, Hazards	Personal injury or death due to external prompt radiation associated with beam
Potential Initiators	Person inadvertently enters enclosure; person fails to leave before beam initiated

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. Operating procedures 2. Worker / User training 3. Review of facility design for radiation safety by C-A RSC 4. Tunnel/target room sweep procedures 5. ACS and PASS door locks and other access controls 6. Audible/visual alarms initiated by ACS and PASSinside enclosures before beam initiation, allowing sufficient time for un-swept individuals to manually stop beam initiation or exit enclosure to stop beam initiation 7. ACS and PASS automatic interlock to stop beam given access violation 8. ACS and PASS controls critical devices to automatically confine beam to enclosure, thus keeping beam out of downstream section with personnel inside

Risk Assessment Following Mitigation

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	() Unlikely	(X) Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

Table A2-6 Risk Assessment for Radiation Exposure from Activated Components

FACILITY NAME: C-AD
SYSTEM: Beam Dump, Other Activated Components
SUB-SYSTEM: N/A
HAZARD: External Radiation from Activated Beam Dump, Activated Magnets and Other Components

Event	Worker / User inside target room or tunnel during beam off periods
Possible Consequences, Hazards	Excessive external dose
Potential Initiators	Improper work planning, procedure violation

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Hazard Mitigation	1. Beam tuning keeps activation of magnets and beam–line components to a minimum 2. Integrated Safety Management program assures proper work planning prior to authorizing start of work 3. Radiological surveys of work areas performed and RWP issued prior to start of work 4. ALARA design and administrative controls assure doses are well below regulatory limits 5. C-A ALARA Committee reviews jobs and facility designs. 6. Worker / User training 7. Radiological postings warn personnel of high dose rates 8. Personnel entering High Radiation Areas must wear alarming self-reading dosimeters

Risk Assessment Following Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-7 Risk Assessment for Conventional/Industrial Hazards

FACILITY NAME: C-AD
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: Noise, Heat, Confined Spaces, Lasers, Rotating Equipment, Pressurized Systems, Hazardous Atmospheres, Magnetic and RF Fields, Hoisting, Rigging, Heights, Cryogenic Fluids, Chemicals, Flammable / Explosive Gases, Falling Objects, Hot Surfaces, Trip Hazards, Welding/Cutting, Excavation, etc.

Event	Injury resulting from industrial hazard
Possible Consequences, Hazards	Worker/experimenter injury or death
Potential Initiators	Improper work planning, procedure violation

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	(X) High Risk	() Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. Integrated Safety Management program assures proper work planning prior to authorizing start of work 2. Worker / User training 3. Review and audit of conventional safety issues by C-A staff and ESH experts during Tier 1, work planning and/or ESH appraisals as required by the BNL Integrated Assessment Program 4. Review of experimental safety by C-A ESRC 5. Review of accelerator system safety by ASSRC 6. Uniform laboratory safety requirements defined by BNL SBMS 7. Environmental review of experiments 8. Industrial hygiene review of experiments 9. New designs incorporate requirements of BNL SBMS and industrial standards for conventional and industrial safety 10. Formal C-AD Worker, Safety and Health Program

Risk Assessment Following Mitigation

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-8 Risk Assessment for Airborne Radioactive Releases

FACILITY NAME: C-AD
SYSTEM: Ventilation
SUB-SYSTEM: Exhaust Systems
HAZARD: Radioactive or Hazardous Materials

Event	Uncontrolled release of airborne radioactive or hazardous materials
Possible Consequences, Hazards	Adverse health effects to workers (public health effects not possible)
Potential Initiators	Improper work planning, violation of procedures, human error

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Hazard Mitigation	1. Integrated Safety Management program assures proper work planning prior to authorizing start of work 2. Worker / User training 3. Review of conventional safety by C-A ASSRC 4. Review of experimental safety by C-A ESRC 5. Safety standards defined by BNL SBMS 6. BNL Environmental Management System 7. BNL Chemical Management System 8. Testing of HEPA filters and periodic replacement as required by BNL SBMS 9. Design incorporates requirements of BNL SBMS and standards for radiation safety

Risk Assessment Following Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-9 Risk Assessment for Liquid Radioactive Releases

FACILITY NAME: C-AD
SYSTEM: Cooling Water System
SUB-SYSTEM: Radioactive Water
HAZARD: Soil and Groundwater Contamination

Event	Spill of activated cooling water to soil
Possible Consequences, Hazards	Groundwater contamination, internal dose to BNL personnel or public
Potential Initiators	Water pressure boundary failure, procedure violation, improper work planning

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Hazard Mitigation	1. Integrated Safety Management program assures proper work planning prior to authorizing start of work 2. Worker / User training 3. Review of conventional and experimentsl safety by C-A ASSRC and ESRC 4. Safety requirements defined by BNL SBMS 5. BNL Environmental Management System 6. BNL Chemical Management System 7. Extensive groundwater monitoring well system and groundwater-sampling program 8. Site suited for easy groundwater plume characterization 9. It would take decades for an un-remediated plume to migrate offsite to contaminate a drinking water well; this assures that even if un-remediated, no one would drink contaminated water 10. Periodic replacement of activated cooling water with fresh water to reduce activity levels in water systems 11. Suffolk County Article 12 Code is followed in the design of cooling water systems and piping that contain significant amounts of tritium 12. The laboratory maintains contingency storage facilities should water tankers with tritiated water develop leaks 13. Tankers stored in Suffolk County registered secondary containments

Risk Assessment Following Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	(X) Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-10 Risk Assessment for Loss of Electrical Power

FACILITY NAME: C-AD
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: Hazards Produced As Power Is Lost To Equipment

Event	Loss of offsite power, local loss of power to C-AD facility
Possible Consequences, Hazards	Personal safety hazards, programmatic loss
Potential Initiators	Loss of electrical power to BNL site or local power loss to C-AD caused by equipment failure or operator error

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Hazard Mitigation	1. Integrated Safety Management program assures proper work planning prior to authorizing start of work 2. Worker / User training 3. Review of conventional safety by C-A ASSRC and BNL ESH Committees 4. Review of experimental safety by C-A ESRC 5. Backup power supplied to required systems to reduce programmatic impact 6. Accelerator automatically shuts down upon loss of electrical power 7. ACS and PASS fail-safe design 8. Emergency lighting 9. BNL and C-AD emergency procedures

Risk Assessment Following Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	() Low Risk	(X) Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-11 Risk Assessment for Fire

FACILITY NAME: C-AD
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: Personal Injury or Equipment Damage

Event	Magnets, power and control cables, laboratory equipment combustion
Possible Consequences, Hazards	Personal injury/death, programmatic impact
Potential Initiators	Loss of cooling to magnets or power supplies, transient combustibles start fire which spreads, electrical component overheating, flammable/combustible gas ignition, human error

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. Combustible loading is minimized at facilities 2. Periodic safety inspections 3. Safety training for Users and staff 4. Fire protection/suppression system is designated safety significant 5. Design reviewed by BNL Fire Protection Engineer 6. Design meets NFPA requirements 7. Emergency ventilation in accelerators 8. Experiments reviewed by C-A ESRC 9. Conventional safety reviewed by C-A ESRC 10. Fire Hazards Analysis completed for C-AD and written/reviewed by a FP Engineer

Risk Assessment Following Mitigation

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

Table A2-12 Risk Assessment for Groundwater Contamination

FACILITY NAME: C-AD
SYSTEM: Soil Shielding
SUB-SYSTEM: N/A
HAZARD: Groundwater Contamination

Event	Groundwater contamination from activated soil
Possible Consequences, Hazards	Internal radiation dose, loss of regulator/public confidence
Potential Initiators	Soil cap failure, excessive beam loss in unexpected locations, cap design/installation errors

Risk Assessment Prior to Mitigation

Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	() High	(X) Medium	() Low	() Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. Beam tunnel and target room impermeable soil caps at known/anticipated beam loss locations 2. Periodic cap inspections 3. Beam tuning procedures to reduce soil activation 4. Operator / Physicist training 5. C-AD Environmental Management System 6. Extensive groundwater monitoring well system and sampling program in place 7. Long travel time for plume to reach BNL site boundary

Risk Assessment Following Mitigation

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

Table A2-13 Risk Assessment for Biological/Medical Hazards

FACILITY NAME: C-AD
SYSTEM: NASA Experimental Facilities
SUB-SYSTEM: NSRL or Beam Line in Building 912
HAZARD: Biological or Medical

Event	Release or contamination by biological or medical hazards
Possible Consequences, Hazards	Illness, programmatic impact
Potential Initiators	Failure to follow procedures, improper review of experiment, equipment failure

Risk Assessment Prior to Mitigation
Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	() High	(X) Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. NSRL facility designed for Biosafety Level 2, which can safely handle blood, body fluids and tissues infected with unknown agents 2. General public excluded from NASA facility 3. Cell Facility separated from Animal Facility in building 4. Animal Facility HEPA filtered 5. Regulated Medical Wastes handled by properly trained BNL Medical Department Personnel 6. Biological Safety cabinets used to protect workers and users 7. Training of the user in safe laboratory practices, including engineered systems and PPE, is given by the BNL Medical Department, commensurate with risk to worker 8. Experiments with human cells and tissues reviewed by BNL Institutional Review Board 9. Transportation of cells, animals, etc., to and from the facility, will be in accordance with BNL requirements 10. Review of experiments by appropriate BNL committees, and by C-A ESRC 11. Review of experiment by industrial hygienist and ECR

Risk Assessment Following Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A2-14 Risk Assessment for Oxygen Deficiency Hazards

FACILITY NAME: C-AD
SYSTEM: Accelerator and Experimental Facilities
SUB-SYSTEM: Cryogenic liquids, inert gas use/storage, Air Conditioning Systems
HAZARD: Oxygen Deficiency

Event	Breathing air displaced causing reduced oxygen concentration
Possible Consequences, Hazards	Illness, asphyxiation
Potential Initiators	Significant release of gases to area or room

Risk Assessment Prior to Mitigation
Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. ODH hazards analyzed and controls in place as per BNL SBMS requirements 2. Use of portable or fixed alarming oxygen concentration monitors 3. Training of Users and Staff 4. Work planning and LOTO 5. Review of ODH hazards and controls by C-AD ASSRC and ESRC 6. Review of ODH hazards and controls by BNL LESHC Cryogenic Subcommittee 7. Cryogenic designs meet ASME Code and appropriate consensus stands designs and testing requirements 8. Confined Space Entry Permitting Program 9. BNL and C-AD emergency procedures 10. Active exhaust ventilation systems supplied by normal and standby power if needed to minimize ODH risk

Risk Assessment Following Mitigation

Consequence	() High	(X) Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	(X) Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement

Table A2-15 Risk Assessment for Hazardous Material Handling

FACILITY NAME: C-AD
SYSTEM: Accelerator and Experimental Facilities
SUB-SYSTEM: Beryllium Vacuum Pipes, Lead Bricks, Asbestos Building Materials
HAZARD: Inhalation of Hazardous Materials

Event	Working with or handling Be, Pb or asbestos items creates airborne concentrations of hazardous materials
Possible Consequences, Hazards	Illness, toxic reactions
Potential Initiators	Improper work planning, violation of procedures, human error

Risk Assessment Prior to Mitigation
Note: Refer to Chapter 4 for an explanation of consequence, frequency and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	() High	(X) Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low

Hazard Mitigation	1. Airborne hazards are analyzed and controls in place as per BNL SBMS requirements 2. Integrated Safety Management program assures proper work planning prior to authorizing start of work 3. Worker / User training 4. Review of conventional safety by C-A ASSRC 5. Review of experimental safety by C-A ESRC 6. Safety standards defined by BNL SBMS 7. BNL Environmental Management System 8. BNL Chemical Management System 9. Testing of HEPA filters and periodic replacement as required by BNL SBMS 10. Work plan incorporates requirements of BNL SBMS and standards for Be, Pb or asbestos safety 11. Active exhaust ventilation systems supplied by normal and standby power if needed to minimize risk

Risk Assessment Following Mitigation

Consequence	() High	(X) Medium	() Low	(X) Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	(X) Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement

Examples of OHSAS 18001 Facility, Area and Job Risk Assessments

This following risk tables were developed using a standard method for developing, using and maintaining risk assessments that meets the requirements of OHSAS 18001 Clause 4.3.1. The procedures can be found in BNL's SBMS.

A "rough draft" estimate of hazards and risks for each area or activity was prepared and is shown in Table A2-16. The list was developed based on previous experience and information on known physical items or jobs in the work areas.

The assessments in the subsequent tables were developed by:

- describing the physical items or activities or jobs present in the area or facility
- identifying the hazards associated with each physical item or job step
- identifying controls in place for each hazard
- determining the Occupancy or Use of the area or Frequency of the job
- estimating the potential Severity of an accident associated with each hazard
- estimating the Likelihood or chances of an injury for each hazard given existing controls
- identifying possible additional controls needed for these hazards
- re-estimating the risk and the % risk reduction if controls were added

An assessment was performed for all areas and jobs listed in Table A2-16. Only a few example assessments are shown here.

The complete listing of Facility Risk Assessments (FRAs) is at http://www.rhichome.bnl.gov/AGS/Accel/SND/facility_and_area_risk_assessments.htm.

The complete listing of Job Risk Assessments (JRAs) is located at http://www.rhichome.bnl.gov/AGS/Accel/SND/job_risk_assessments.htm

These assessments are updated each year or when modifications to facilities, areas or jobs occur. As necessary, the Department management schedules and assigns appropriate personnel to conduct or update an FRA or JRA in conjunction with a Critique, Occurrence, near miss or non-conformance associated with a job or a facility.

Table A2-16 Risk Assessment Strategy for Jobs and Work Areas

Area or Activity	**Description**	**Priority**	**Reason**
General Electrical Issues	Standard electrical installations and activities throughout the facility	Medium	Minor shocks have occurred the last few years from legacy wiring. Overheating occurs occasionally due to the inventory of components. Some open ATS items related to improving electrical safety. Many OSHA violations found by OSHA Team.
General Fire Issues	General fire protection throughout the facility; cover special areas separately	Medium	Fire protection systems are old but operable. Upgrades are needed and ADS forms are outstanding and awaiting funding. Fires are possible significant programmatic problems. Minor fires have occurred in the last few years. FHAs are currently being revised for C-AD facilities. BNL only had a single FP Engineer for many years until end of 2004.
General Radiation Issues	General radiation protection issues throughout the facility	Low	In general, radiation is not a significant health risk but is a compliance issue. Access controls provide protection against high hazard radiation.
General ODH Issues	General oxygen deficiency issues throughout the facility	Low	ODH analyses have provided a good approach to worker safety in the newer facilities.
General Housekeeping Issues	General housekeeping issues throughout the facility	Medium	Work is sometimes finished without area cleanup completed. Causes restricted walkways, slip hazards, increased fire loading. Tier 1 inspections cite this numerous times. Many OSHA findings related to housekeeping.
Cryogenic Refrigerator Room	1005R for RHIC He expansion as part of the refrigeration process	Medium	ODH 1 area. A lot of equipment under pressure. Cryogenic fluids. High ambient temperature in building in warm weather.
Cryogenic Compressor Room	1005H for RHIC He compression as part of the refrigeration process	Medium	High pressure helium. Highest noise levels of all C-AD facilities.
He Reliquifier	1005E for conversion of He gas to liquid for storage	Low	Recently reviewed by ASSRC.
Shops	Mechanical and electrical maintenance	Medium	Recent injuries. Improved training on machine operations is needed.
Offices	General offices with computer usage	Medium	Ergonomic injuries have been experienced.
STAR	RHIC experiment	Low	Reviewed by ESRC annually. User injury rates are extremely small.

Area or Activity	Description	Priority	Reason
PHENIX	RHIC experiment	Low	Reviewed by ESRC annually. User injury rates are extremely small.
PHOBOS	RHIC experiment	Low	Reviewed by ESRC annually. User injury rates are extremely small.
BRAHMS	RHIC experiment	Low	Reviewed by ESRC annually. User injury rates are extremely small.
NSRL	NASA Experimental Building	Low	Reviewed by ESRC annually. User injury rates are extremely small.
Building 912/U-Line/ g-2	AGS experiments	Medium	Roof leaks causing walking/working surface issues. A lot of work is taking place such as decommissioning of old beam lines in preparation for future experiments.
Warehouses/storage facilities	Storage of materials and movement of materials	Low	Not a lot of material movement.
Equipment Testing Areas	Permanent testing locations for C-AD equipment	Medium	Test areas have not been specifically reviewed in the recent past.
EBIS	Building 930A	Medium	Not reviewed in detail for a few years.
eCooler	Building 939	Low	Recent reviews by ASSRC and RSC.
Waste Yard	Building 960 area	Low	No injuries in recent past.
90 Day Area/Satellite Areas	Various locations	Low	No injuries in recent past.
Accelerators	Booster, AGS	Low	No injuries in recent past.
Preinjectors	Linac. Tandem	Low	No injuries in recent past.
Collider	RHIC tunnel and service/support buildings	Low	No injuries in recent past.
Locked Electrical rooms/Locked Electrical Caged Areas	930B, 1005E, 1007W, 928 basement, 919B, 911B relay room	Low	No injuries in recent past.
Transportation	Vehicle use for moving materials within and interfacing with C-AD property	High	Recent dropped load from flatbed truck.
Material handling-machinery	Cranes, forklifts, etc.	High	Recent forklift dropped load.
Material handling-manual	Human lifting	Medium	Back injuries have occurred.
Electrical work- routine	<600 V	Medium	Hazard is experienced daily by many workers. Controls have been effective.

Area or Activity	**Description**	**Priority**	**Reason**
Electrical work-high energy	>600 V	Medium	Hazard is experienced daily by many workers. Controls have been effective.
Electrical working hot	Working on energized equipment	Medium	High consequences. Controls have been effective.
Radiation/contamination work	Work in posted areas	Low	Compliance issue. Very detailed controls in place and significant oversight.
Work with lasers	Lasers at C-AD facilities	Medium	Recent injury at Chemistry but external review of BNL laser safety recently completed.
Pressurized system work	Liquid and gas systems	Medium	Hazard is experienced daily by many workers. Controls have been effective. Cryogenic personnel responded to a few pressure boundary leaks in the last few years.
Vacuum system work	Beam lines and vacuum system equipment	Low	No recent injuries.
Biological/animal work	NSRL or Building 912	Low	In one facility and good controls in place.
Cable pulling	Various locations	High	Done a few times per year by many workers with varying experience. Injuries have occurred in the past.
Operations	MCR, CAS, Siemens, Cryogenics, Tandem	Low	No recent injuries.
Emergency response	LEC, DEC and emergency forces	Low	No recent injuries.
Waste handling	Radioactive, hazardous, industrial wastes	Low	No recent injuries.
Work with hazardous materials	Be, lead, chemicals, etc.	Low	No recent injuries.
Adding cooling tower chemicals	Adding water treatment chemicals	Medium	A Water Group technician inhaled water chemical vapors in the last year that caused concern. No recent injuries. CMS in place.
Hi-pot testing	Various locations	Medium	High consequences and done frequently.
Crane use by C-AD staff	Use by non-riggers	Medium	Recent rigging occurrences require a closer look here.
Forklift use by C-AD staff	Use by non-riggers	Medium	Recent forklift occurrences require a closer look here.
Welding/Welding Helper	Various locations	Medium	Recent issue with welder’s helper getting arc-eye.
Tours	Various locations	Low	No injuries or perceived health issues. Good escort program in place.

Table A2-17 Area/Facility Risk Assessment – Facility Wide Electrical

Name(s) of Risk Team Members: P. Cirnigliaro, A. Etkin, R. Karol, E. Lessard, J. Maraviglia, D. Passarello, A. Piper, R. Savage, J. Scott, M. Van Essendelft	Point Value → Parameter ↓	1	2	3	4	5
Area/Facility Description Title: Collider-Accelerator Department Area/Facility # (if applicable): Facility Wide – FRA 1	Occupancy or Use	<u><</u>once/year	<u><</u>once/month	<u><</u>once/week	<u><</u>once/shift	<u>></u>once/shift
Area/Facility Description: Facility Wide Electrical	Severity	First Aid Only	Medical Treatment	Lost Time	Partial Disability	Death or Permanent Disability
Approved by: *E. Lessard* Date:6-30-04 Rev.#: 2	Likelihood	Impossible	Unlikely	Possible	Probable	Multiple
Reason for Revision (if applicable): FRA number added. Standard hazard nomenclature added.				Comments:		

			Before Additional Controls					After Additional Controls				
Physical Item or Activity	Hazard(s)	Control(s)	**Occupancy A**	**Severity B**	**Likelihood C**	**Risk* AxBxC**	Control(s) Added to Reduce Risk	**Occupancy A**	**Severity B**	**Likelihood C**	**Risk* AxBxC**	% Risk Reduction
Electrical Equipment & Power Supplies BNL Class A & B <250 VAC; <1000Vdc	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; GFCI; grounding standards; emergency procedures	5	4	2	40	A new computer based LOTO program was introduced to better track LOTOs. C-AD supervisors removed temporarily stored items away from disconnects and breaker panels. Technicians, engineers and electricians were trained regarding the proper use of temporary wiring. Temporary wiring installations are now tracked and when due they are removed or converted to permanent wiring. OPM 13.6.2 was modified to state that an ECN is required prior to issuing a work order for all work on the power distribution system. A drawing or a sketch and a printed label or panel directory is now issued with the work order. Supervisors now indicate that all labeling was completed. Electricians have been assigned to label existing disconnects for a few hours each week.	5	4	2	40	The likelihood of an injury was reduced but it is not impossible. Occupancy and severity do not change.

Electrical Equipment & Power Supplies BNL Class C <600 VAC; <6000 VDC	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; GFCI; grounding standards; emergency procedures; two-person rule for hot work	4	5	2	40							
Electrical Equipment & Power Supplies BNL Class C <600 VAC; <6000 VDC	Arc blast; burn	Procedures, training, PPE	4	5	2	40							
Electrical Equipment & Power Supplies BNL Class D >600 VAC; >6000 VDC	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; GFCI; grounding standards; emergency procedures; safety watch for hot work	2	5	2	20							
Electrical Equipment & Power Supplies BNL Class D >600 VAC; >6000 VDC	Arc blast; burn	Procedures, training, PPE	2	5	2	20							
Extension Chords; Temporary Wiring And Power Strips	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; qualified electricians and technicians; GFCI; grounding standards	5	4	2	40							
Transformer And Switch Yards	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; installations comply with applicable codes; procedures; training; LOTO; qualified electricians; postings; locked areas; work planning; grounding standards; emergency procedures; grounding before work start	2	5	2	20							
Transformer And Switch Yards	Arc blast	PPE; procedures; training; qualified electricians	2	5	2	20							
Underground/Overhead Cables/Wiring	Shock or electrocution	All equipment is listed or reviewed by CEE; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; qualified electricians; postings; work planning; digging permit	2	4	4	32							

Batteries/UPS	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; grounding standards; emergency procedures	3	4	3	36						
Batteries/UPS	Molten spray	PPE; procedures; training	3	3	2	18						
Batteries/UPS	Being struck by an object, such as due to hydrogen gas explosion	PPE; procedures; training	3	3	2	18						
Standby Generators	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; grounding standards; emergency procedures	2	5	2	20						
Standby Generators	Noise	Hearing protection	5	4	2	40						
Standby Generators	Entanglement	Guards for rotating parts	5	5	2	50						
Siemens And Westinghouse MG Sets	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; grounding standards; emergency procedures	5	5	2	50						
Siemens And Westinghouse MG Sets	Noise	Hearing protection	5	4	2	40						
Siemens And Westinghouse MG Sets	Becoming caught in or compressed by equipment	Crash button for shut down; guards for rotating parts	5	5	2	50	It is planned that postings be upgraded to enter Siemens MG Room or to lock the MG Room					
General Wiring; Cable Trays; Buss Work	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; GFCI; grounding standards; emergency procedures	5	5	2	50						

Buss or electrical equipment cooling water	Being struck by an object from water jet or pressure	Tier 1 inspections; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; work planning	4	2	3	24							
Motor Control Centers; Panels And Wall Sockets	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; grounding standards	4	5	3	60							
Motor Control Centers; Panels And Wall Sockets	Arc blast; burn	PPE; training; procedures	4	5	3	60							
Electrical Disconnects And Switches	Arc blast; burn	Procedures, training, PPE	4	4	3	48							
Electrical Disconnects And Switches	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; GFCI; grounding standards; emergency procedures; two-person rule for hot work	4	4	3	48							
Circuit Breakers	Arc blast; flash	All equipment is listed or reviewed by CEE; PPE; procedures; training	4	3	3	36							
Appliances And Computers	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; qualified electricians and technicians; cabinet interlocks; postings; locked areas; guarding; work planning; GFCI; grounding standards; emergency procedures; two-person rule for hot work	5	3	2	30							
Vacuum Pumps	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; postings; work planning; grounding standards	3	5	3	45							
Magnets	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; postings; locked areas; guarding; work planning; grounding standards	5	4	2	40							

Magnets	Magnetic fields	Posting; fencing; warnings; magnet design reviews; field measurements; medicals; work planning; ASSRC reviews; work planning	2	3	3	18						
Capacitors/inductors	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; postings; locked areas; guarding; work planning; grounding standards	3	5	2	30						
Beam Components and Instrumentation	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; distribution drawings; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; qualified electricians and technicians; postings; locked areas; guarding; work planning; grounding standards	3	4	3	36						
Beam Components and Instrumentation	Being struck by an object, due to moving parts remotely operated	Guards for moving parts	2	3	3	18						
Electrical Powered Hand Tools	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; procedures; training; labeling; work planning; GFCI; grounding standards; double insulation	5	3	3	45						
RF Cavities	Shock or electrocution	All equipment is listed or reviewed by CEE; Tier 1 inspections; disconnected cable policy; installations comply with applicable codes; procedures; training; LOTO; Kirk keys; working hot permits; ASSRC/ESRC reviews; locked areas; guarding; work planning; grounding standards; emergency procedures	3	5	3	45						
RF Cavities	Rf field	RF gaskets; interlocked areas	3	2	2	12						
RF Cavities	Noise	Hearing protection	3	2	2	12						
RF Cavities	Radiation exposure from X-rays	Access controls; shielding; training; RCD surveys; postings; locked areas; procedures for test areas; RWP; work planning	5	4	2	40						
Confined Spaces - Metal	Increased chance of shock due to proximity to conducting surfaces	All equipment is listed or reviewed by CEE; work planning; grounding standards; GFCI	2	4	2	16						

Further Description of Controls Added to Reduce Risk: OSHA Teams visited C-AD during the period October 20 through October 31, 2003. Many electrical OSHA non-compliances were recorded. Many disconnects were found to be obstructed by large transformers, stairs, sinks, water heaters, walls, pumps, uninterruptible power supplies, fixed fire-protection equipment or building girders. Many were obstructed by temporarily stored items. Many disconnects such as circuit breakers were not labeled in English, spares were not marked, or the labels were faded. The C-AD system of labeling with numbers is not accepted by OSHA. Temporary wiring was being used where permanent wiring should have been installed. Flexible cord was being used to power fixed equipment such as work benches or ventilation systems and was being strung through walls, ceilings and doors or to power distribution boxes. Long 20-foot flexible cord was used on vibrating equipment. Flexible cord was used to feed metal outlet boxes that lay on the floor. All the OSHA items are being tracked and closed on a schedule commensurate with funding.

*Risk:	0 to 20	21 to 40	41-60	61 to 80	81 or greater
	Negligible	Acceptable	Moderate	Substantial	Intolerable

Table A2-18 Job Risk Assessment – Cable Pulling

Name(s) of Risk Team Members: E. Lessard and D. Passarello	Point Value → Parameter ↓	1	2	3	4	5
Job Title: Cable Pulling Job Number or Job Identifier: JRA 12	Frequency (B)	≤once/year	≤once/month	≤once/week	≤once/shift	>once/shift
Job Description: Removing cable from cable tray or adding new cable to tray in various locations throughout the complex.	Severity (C)	First Aid Only	Medical Treatment	Lost Time	Partial Disability	Death or Permanent Disability
Training and Procedures List (optional): Approved by: *E. Lessard* Date: 6-30-04 Rev. #: 0	Likelihood (D)	Impossible	Unlikely	Possible	Probable	Multiple

Stressors (if applicable, please list all): Unwilling helpers, heat	Reason for Revision (if applicable):	Comments:

				Before Additional Controls						After Additional Controls						
Job Step / Task	Hazard	Control(s)	Stressors Y/N	# of People A	Frequency B	Severity C	Likelihood D	Risk* AxBxCxD	Control(s) Added to Reduce Risk	Stressors Y/N	# of People A	Frequency B	Severity C	Likelihood D	Risk* AxBxCxD	% Risk Reduction
LOTO Power to Cables in Tray	Electrocution	Work planning, LOTO training	N	2	1	5	2	20								
Pull In or Remove AC or DC Cables	Being struck against an object - cuts and skin abrasions from working in tight spaces	Knee and elbow pads, steel-toe shoes, gloves	Y	5	1	3	4	60	Purchase gloves that allow one to feel cable ties, thus no need to keep removing gloves	Y	5	1	3	3	45	25%
Pull In or Remove AC or DC Cables	Overexertion – injuries caused by excessive lifting, pushing, pulling, holding, carrying or throwing of an object	Team coordination to share the pulling forces equally, more guys working together leads to less strain	Y	5	1	3	4	60	Recommend to management that a regular team be used for cable pulls. See Further Description below.	Y	5	1	3	3	45	25%
Pull In or Remove AC or DC Cables	Being struck by an object, such as a tool falling on a worker from above	Safety glasses, hard hats	Y	5	1	3	3	45								

Pull In or Remove AC or DC Cables	Falls to lower level, such as falling from a ladder or over a railing	Fall protection (railings or scaffolding or tie-offs or man-lifts), OSHA compliant ladders, barricade around work area	Y	5	1	3	4	60	On rare occasions, men have to stand on cable tray. This type of work should be considered high hazard and not be done	Y	5	1	3	3	45	25%
Pull In or Remove AC or DC Cables	Contact with temperature – extremes that result in such injuries as heat exhaustion, frost bite or burns	Fans indoors, water outdoors	Y	5	1	3	3	45	Supply water to cable pull team	Y	5	1	3	2	30	33%
Pull In or Remove AC or DC Cables	Bodily reaction – injuries resulting from bending, climbing, loss of balance and slipping without falling	Team coordination to share the pulling forces equally	Y	5	1	3	4	60	Recommend to management that a regular team be used for cable pulls. See Further Description below.	Y	5	1	3	3	45	25%
Pull In or Remove AC or DC Cables	Falls on same level	Shoes with slip resistant soles	Y	5	1	3	4	60	Purchase shoes with slip resistance soles, current oil resistant soles become hardened and get slippery	Y	5	1	3	3	45	25%
Pull In or Remove AC or DC Cables	Tics	White suits, tic spray	Y	5	1	3	3	45								
Moving Cable Spools and Pulling Cable Off Spools	Bodily reaction – injuries resulting from bending, climbing, loss of balance and slipping without falling	Use experienced personnel who know how to move a spool with little manual force, bring cable close to work area using lifting equipment, use jacks to hold cable off ground during long pull	Y	5	1	3	4	60	Investigate the use of a cable spool trailer that can be towed by a vehicle	Y	5	1	3	3	45	25%
Connect AC or DC Cables	Becoming caught in or compressed by equipment	Following manufacturer's instructions for safe use of hydraulic crimper, PPE.	N	2	1	5	2	20								

Further Description of Controls Added to Reduce Risk:

The current practice of supplementing the regular 2-man cable-pull team with local help often leads to unwilling workers who don't share the weight, which leads to back injuries and strains to other people on the pull to react to the extra forces. Unwilling workers feel this job is beneath their status. Inexperienced people are not aware of the best way to position their bodies for this job. Experienced people know how to lift cables, work as a team and move cable rolls with relative ease.

Man lifts should be bettor maintained. Recent experience shows that man lifts are being brought in by crane when needed but when they are used to help reach a cable tray, the man-lifts do not work. This slows a job down for days and creates job stressors such as time pressure and reduced number of breaks. Breaks are important for the crew since they must often take a few minutes to gather their strength after a difficult pull. Man-lifts should be checked and be fully operational before being lifted into cable-pull work areas.

Radio communications between team members inside and outside shielded areas is difficult using the F2 frequency. This is due to a lot of traffic on that frequency when a fire/rescue call goes out. Investigate alternate communications. Good communications are needed to share the pulling equally and avoid strains and back injuries.

*Risk:	0 to 20	21 to 40	41-60	61 to 80	81 or greater
	Negligible	Acceptable	Moderate	Substantial	Intolerable

Collider-Accelerator Department Shielding Policy

The main features of the shielding policy for C-AD facilities are currently delineated in the Collider-Accelerator Department Operations Procedure Manual.[1, 2] The principal components of this policy are reviewed here for completeness. The primary purpose of the shielding policy is to assure that all radiation related requirements and administrative control levels are satisfied. Specifically, the Collider-Accelerator Department's Radiation Safety Committee reviews facility-shielding configurations to assure:

1. Annual site-boundary dose equivalent is less than 5 mrem.
2. Annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities is less than 25 mrem.
3. Maximum dose equivalent to any area where access is not controlled is limited to less than 20 mrem during a fault condition.
4. For continuously occupied locations, the dose equivalent rate is ALARA but in no case greater than 0.5 mrem in one hour or 20 mrem in one week.
5. Dose equivalent rates where occupancy is not continuous is ALARA, but in no case exceeds 1 rem in one year for whole body radiation, or 3 rem in one year for the lens of the eye, or 10 rem in one year for any organ.

In addition to review and approval by the Radiation Safety Committee, final shield drawings must be approved by the Radiation Safety Committee Chair or the ESHQ Associate Chair. Shield drawings are verified by comparing the drawing to the actual configuration. Radiation surveys and fault studies are conducted to verify the adequacy of any new or modified shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed by additional Collider-Accelerator Department procedures, which are not elaborated here.[3] Any modifications to shielding configurations are likewise closely proscribed. Each facility and experiment is assigned a Liaison Physicist and Liaison Engineer. The Liaison Physicist is responsible, in consultation with the Radiation Safety Committee where appropriate, for determining safe conditions for any shielding modifications. The Liaison Engineer is responsible for ensuring that the safe conditions are met, for effecting any modification, and for notifying other responsible Collider-Accelerator Department personnel, including the Operations Coordinator, as well as experimenters both prior to and on completion of the modifications. Additional procedures exist to ensure that policy with respect to control of radioactive shielding is implemented, which are not elaborated here.

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[1] http://www.agsrhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-12.PDF Procedure for Review of Collider-Accelerator Department Shielding Design

[2] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch08/08-13.PDF Collider-Accelerator Department Procedure for Shielding/Barrier Removal, Removal of Primary Area Beam Line Components, or Modifications

[3] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-09.PDF Fault Study Procedure for Primary and Secondary Areas